# Editor's acknowledgments

Having completed the Proceedings for the ICBEN-Congress 2011 in London, UK I have the feeling that I might be the only one who did not learn from the last congress (2008 in Foxwoods CT, USA) for which I have edited the proceedings as well. Back then the editing of the previous proceedings was a rather hectic, occasionally even chaotic and by all means a time-consuming task. This time was even worse. The number of contributions was greater and some stress was caused by my in any case highly appreciated colleagues. While some of them sent their papers soon after acceptance, most sent it around the deadline, many even thereafter or never. Moreover, despite the provision of a template many colleagues preferred to follow their habits in using their own formats, fonts, letter sizes, modes of literature citations and arrangement of figures and tables etc. Thus, the editor's task was not only to arrange the papers but to carefully revise each paper that revealed a wealth of typing errors to be eliminated.

Coping with these problems requires a competent team that keeps an overview at any time and in any situation. I am grateful for having worked with Susanne Lindemann and Jessika Koentjoro. Both of them did a great job and far more than one would expect from a technical editor. That included not only the formatting of figures, texts and tables, the arrangement of the papers but – and this part was most strenuous – the evaluation concerning correct citations of the literature. In case of (rather frequent) inconsistencies they both had an extended correspondence with the authors until the problem was solved. With both of them I would take over that task again.

Dortmund, July 2011

Barbara Griefahn

**The final paper was not available at deadline.**

# Hearing loss is a public health problem determined by noise and life-course events

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ABSTRACT

In Europe, there are 26 % of adults with a bilateral hearing problem that impairs their ability to hear in noisy situations substantially and a further 2 % who have substantial unilateral hearing problems, impacting substantially on their ability to locate a sound (e.g. car, bus, voice). The prevalence is highly related to age. There is no remission. There is a similar prevalence worldwide on an age adjusted basis. About a quarter of this may be attributable to noise. A small but substantial number of people acquire hearing loss as a complication of cancer treatment and there is no evidence that their hearing problems are diagnosed earlier. We can reduce the impact that noise and toxins have on the cochlea and on the auditory cortex, but age is still by far the biggest problem we have to tackle! In terms of noise, there are four main sources - background, social, environmental and occupational noise. How do we tackle all of these? Which are the most important messages for individuals, communities and governments? In addition to noise, there is accumulating evidence that early social and biological factors may influence hearing in middle age. In addition there are factors such as alcohol, tobacco and diabetes that are also associated with high frequency hearing loss at this age. This offers the prospect that we should combine public health effort with efforts to tackle environmental and personal factors affecting health and hearing health; this may be more effective than tackling the hearing conservation issues alone.

# Healthy diets and dietary supplements: recent changes in how we might think about hearing conservation

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## INTRODUCTION

Hearing conservation strategies have primarily been targeted at diminishing the level and duration of sound exposure on the person or population of interest, usually through use of environmental engineering or use of personal hearing protection devices (HPDs). Numerous factors limit the application of these two conservation methods--- environmental controls can be limited by cost and technological limits; hearing protection devices can be limited by user compliance and most notably bone/tissue conduction imposed (Berger 2003). Pharmaceutical and/or nutraceutical strategies are therefore of high interest. As the scientific understanding of noise-induced hearing loss (NIHL) has advanced with respect to metabolic pathways activated by noise, age, and ototoxic drugs, such strategies are increasingly likely to succeed, and, importantly, a healthy diet may also prove important. We now know that metabolic stress drives free radical formation, leading to cell death and hearing loss. Three key findings have supported development of novel antioxidant strategies for protection. Free radicals are produced during noise (Yamane et al. 1995; Ohlemiller et al. 1999b); free radical production is long-lasting, with cell death occurring in concert with peak free radical production (Yamashita et al. 2004); and free radical scavengers directly mediate cell death and hearing loss (Yamashita et al. 2005). For detailed discussion of cell death after noise insult, readers are referred to Le Prell et al. (2007b); for detailed update on emerging therapeutics that take advantage of free radical scavenging properties, readers are referred to Le Prell & Bao (2011).

Endogenous protection against free radical insult is mediated via superoxide dismutase (SOD) (Ohlemiller et al. 1999a; Cassandro et al. 2003), catalase (Konings et al. 2007), and glutathione (Usami et al. 1996; Yamasoba et al. 1998), as well as glutathione peroxidase, an enzyme that speeds glutathione reactions (Ohlemiller et al. 2000). The precursors needed for endogenous SOD, catalase, and glutathione production are obtained from dietary sources, suggesting the potential for dietary nutrient intake to importantly influence hearing health, and vulnerability to noise or other insults. This paper focuses on the role of dietary nutrients including vitamins, minerals, and macronutrients (i.e. carbohydrates, fat, and protein) in maintenance of normal hearing and/or prevention of hearing loss. For additional more detailed review, readers are referred to Le Prell and Spankovich (2012).

### Vitamins

<u>Vitamin A</u>: Retinol is the non-oxidized form of vitamin A; retinoic acid is the oxidized form. Both pre- (Ahn et al. 2005), and post- (Shim et al. 2009) noise treatment with retinoic acid reduce NIHL; pre-treatment provides better protection than post. ß-carotene is the main source of pro-vitamin A in the diet; it is metabolized to retinol and retinyl esters (i.e., vitamin A) and stored in the liver. When sufficient vitamin A stores exist, metabolism to vitamin A ceases and ß-carotene circulates in plasma. Vitamin A deficiencies increase NIHL (Biesalski et al. 1990), suggesting an important

role for vitamin A in endogenous defense. Indeed, increased serum levels of retinol and pro-vitamin A carotenoids were associated with decreased prevalence of hearing impairment in a community-based epidemiological study in Japan (Michikawa et al. 2009). Dietary sources of vitamin A include liver, milk and cheese; sources of ß-carotene include carrots, spinach, kale, and collard greens (National Institutes of Health Office of Dietary Supplements 2006). There are other carotenoids that are good antioxidants, but which are not sources of vitamin A. One example is lycopene. Lycopene intake was highly correlated with better auditory function in an adult population (Spankovich et al. 2011). Tomato-based products are the primary dietary source of lycopene.

<u>B Vitamins</u>: These include thiamine (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), biotin (B7), folic acid/folate (B9), and cobalamin (B12).

*Vitamin B9.* The natural form of B9 is folate; folic acid is a stable synthetic form (FAO/WHO 2001). Although Berner et al. (2000) reported no relationship between age-related hearing loss (ARHL) and folic acid levels in plasma (Berner et al. 2000), a 3-year study in older adults revealed slower progression of ARHL at low frequencies in subjects receiving folic acid (Durga et al. 2007). Changes were small: 1.0 dB vs 1.7 dB change in PTA at 0.5, 1, and 2 kHz. However, as noted by Dobie (2007), if the changes continued to accrue each year (“a big if”), one might eventually expect a decrease in the proportion of hearing aid candidates at age 75 years. Baseline folate levels in participants were about half the level reported for people living in the US, where folic acid is a normal food additive; the efficacy of supplements may vary in populations with with improved baseline intake. Leafy green vegetables (spinach, turnip greens), citrus fruits and juices, and dried beans and peas are natural folate sources, cereal is a good source of folic acid (National Institutes of Health Office of Dietary Supplements 2009).

*Vitamin B12.* It is not known whether normal dietary intake of vitamin B12 influences hearing status. However, B12 supplements reduced temporary threshold shift (TTS) in human subjects (Quaranta et al. 2004). B12-treated subjects received 1 mg cyanocobalamin/day x 7 days, followed by a 5 mg dose on the eighth day; controls received placebo injections. Serum B12 was significantly increased, and TTS was decreased at 3 kHz in B12 treated subjects. These doses are greater than can be achieved via diet alone. Beef liver and clams are the best B12 sources; fish, meat, poultry, eggs, milk, and other dairy products, also contain vitamin B12 (National Institutes of Health Office of Dietary Supplements 2010a).

<u>Vitamin C</u>: Unlike virtually all other mammals, humans require dietary vitamin C (Chatterjee 1973; 1975). Vitamin C reduced NIHL in guinea pigs (McFadden et al. 2005). In addition, mice that have been genetically modified such that they cannot synthesize vitamin C have greater ARHL and decreased spiral ganglion cell density compared to wild-type controls, and knock-out mice maintained on high-level vitamin C supplements (Kashio et al. 2009). In human populations, increased intake of vitamin C was linked to improved low-frequency hearing outcomes (Spankovich et al. 2011). Good dietary sources include citrus fruits (oranges, grapefruit) and their juices, red and green peppers, and kiwi; other fruits and vegetables which have vitamin C include broccoli, strawberries, cantaloupe, baked potatoes, and tomatoes (National Institutes of Health Office of Dietary Supplements 2010b).

Vitamin D: Vitamin D was suggested to have a role in auditory function given studies demonstrating compromised auditory function in vitamin D deficient patients. Vitamin D treatment improved hearing thresholds in some, but not all, cases (Brookes & Morrison 1981; Brookes 1983). Vitamin D deficiency has also been linked with prolonged N1 latencies in rats (Ikeda et al. 1987). In mice that lack vitamin D receptors (VDR), threshold sensitivity in young (<6 month), and adult (7-14 month old) mice is equivalent to wild-type mice with vitamin D receptors; however, when aged mice (>15 months old) are compared, VDR mice have worse hearing than age-matched wild-type mice (Zou et al. 2008). Deficits also occur with vitamin D intoxification during aging. The *klotho* mouse does not regulate vitamin D levels, resulting in high serum levels for vitamin D3. *Klotho* mice develope hearing loss at an earlier age than wild type controls, but, maintenance on a vitamin D deficient diet rescues their hearing (Carpinelli et al. 2011). In contrast, a case of a human patient with vitamin D intoxification and existing hearing loss revealed no recovery of hearing even with long-term (20 months) treatment (Allen & Shah 1992). The best sources of vitamin D are fatty fish, such as salmon, tuna, and mackerel; beef liver, cheese, egg yolks, and mushrooms provide small amounts (National Institutes of Health Office of Dietary Supplements 2011). Per that report, while almost all of the U.S. milk supply is vitamin-D fortified, foods made from milk (cheese, ice cream) are not usually fortified.

Vitamin E: Vitamin E is a generic term used to capture all eight members of the tocopherol family. Vitamin E (delivered as synthetic vitamin E, Trolox, or α-tocopherol) reduces NIHL (Rabinowitz et al. 2002; Hou et al. 2003; Yamashita et al. 2005), as well as cisplatin-ototoxicity (Lopez-Gonzalez et al. 2000; Teranishi et al. 2001; Kalkanis et al. 2004). Protection is dose dependent with higher doses providing the best protection. Increased intake of vitamin E has also been linked to improved hearing outcomes in humans (Spankovich et al. 2011). The best sources of vitamin E include vegetable oils (wheat germ, sunflower, safflower) and nuts (peanuts, hazelnuts, and, especially, almonds) and seeds (sunflower seeds) oils; other oils (corn, soybean) and green vegetables (spinach, broccoli) also provide some vitamin E (National Institutes of Health Office of Dietary Supplements 2010c).

## Minerals

Potential roles for several dietary minerals have been suggested.

Magnesium (Mg): Mg supplements reduce NIHL (Scheibe et al. 2000; Haupt & Scheibe 2002; Scheibe et al. 2002; Attias et al. 2003; Haupt et al. 2003); Mg deficient diets increase NIHL (Ising et al. 1982; Joachims et al. 1983; Scheibe et al. 2000). Two double-blind placebo-controlled studies report Mg reduces human NIHL (Joachims et al. 1993; Attias et al. 1994; Attias et al. 2004). However, dietary Mg does not confer protection. Plasma Mg was not reliably correlated with NIHL in male U.S. Army soldiers with exposure (8-18 years) to weapons noise (Walden et al. 2000). Bulgur, oat bran, barley, seeds, beans and spinach are good sources of Mg (US Department of Agriculture 2010).

Selenium (Se): Se was suggested to protect the inner ear given reduced hearing loss in workers with the highest plasma Se levels (Chuang et al. 2007). Brazil nuts, fish, and poultry are good sources of Se (US Department of Agriculture 2010). Other studies have used a synthetic organoselenium compound: ebselen. Several studies demonstrated reduced NIHL with ebselen (Pourbakht & Yamasoba 2003; Lynch et al. 2004; Lynch & Kil 2005; Kil et al. 2007). A Phase I Safety Study using doses of 200-

1600 mg was conducted; 38 % of subjects in each group (placebo, treated) reported adverse events categorized as possibly related to the treatment (Lynch & Kil 2009). The most commonly reported adverse event in both groups was headache. Ebselen is advancing into Phase II efficacy trials (Lynch & Kil 2009).

Copper (Cu), Zinc (Zn), Iron (Fe), and Manganese (Mn): SODs contribute to endogenous defense; they speed destruction of the highly toxic superoxide radical into less toxic free radicals. There are multiple SODs, each with different metal cofactors: Cu and Zn (Cu-Zn-SOD), Fe (Fe-SOD), Mn (Mn-SOD), or Ni (Ni-SOD). Human SOD1 (Cu-Zn-SOD) is found in cytoplasm, human SOD2 (Mn-SOD) is found in mitochondria, and human SOD3 (Cu-Zn-SOD) is extracellular. Genetic variation in human SOD1 (Liu et al. 2010) and SOD 2 (Fortunato et al. 2004; Chang et al. 2009) mediates vulnerability to NIHL in humans, consistent with data from mice that cannot produce SOD1 (Ohlemiller et al. 1999a). With respect to dietary supplements, Fe and Zn have been evaluated. Fe supplement by itself does not appear to influence auditory function; however, Fe in combination gentamicin exacerbates gentamicin-induced hearing damage (in guinea pigs, Conlon & Smith 1998). Zn has also been considered. Zn supplements were recently reported to reduce sudden sensorineural hearing loss in a randomized, placebo-controlled clinical trial (Yang et al. 2011). Tinnitus studies, however, have reported small benefits that are not statistically reliable (Arda et al. 2003), or, no differences (Paaske et al. 1991; Yetiser et al. 2002).

Calcium (Ca), Potassium (K), and Sodium (Na): Ca, K, and Na are critical for endocochlear potential, ion channel regulation, second messenger function, mechanoelectrical transduction, synaptic transmission, and efferent regulation (for recent reviews: Wangemann 2006; Frolenkov 2009). However, there has been practically no research on dietary Ca, K, and/or Na and potential effects on the auditory system. The one exception is the recommendation of low-sodium diets for the treatment of Meniere's disease. It remains the standard of care (Devaiah & Ator 2000; Minor et al. 2004; Gates 2005), even though scientific support is lacking (Thai-Van et al. 2001).

**Vitamin/Mineral Combinations**

Combinations of antioxidants are appealing given the potential to scavenge multiple free radicals, in multiple cell structures, and also known synergies, such as the observation that vitamin C contributes to the "recycling" of vitamin E. With respect to the auditory system, the combination of □-carotene, vitamins C and E, and Mg has reduced NIHL in animal models (Le Prell et al. 2007a; Tamir et al. 2010; Le Prell et al. 2011a; 2011b). Combinations have also been evaluated in human patients. Reductions in cisplatin-induced hearing loss were reported in cancer patients receiving a combination of vitamins C and E, and Se (Weijl et al. 2004). However, there were no significant differences between placebo and control with respect to hearing loss; significant differences were limited to high frequency hearing loss found when comparisons included only patients with the highest plasma concentrations of the three nutrients. Additional data on dietary supplements come from Takumida and Anniko (2009), who treated elderly patients with a combination of vitamin C, □-lipoic acid, and rebamipide. Enthusiasm for that study is weakened by the lack of a placebo control. Dietary data are difficult to interpret with respect to interactions among nutrients. For example, higher carbohydrate, vitamin C, vitamin E, riboflavin, magnesium and lycopene intakes were all significantly associated with better auditory function, whereas higher cholesterol, fat and retinol intakes were significantly associated with poorer auditory function (Spankovich et al. 2011). The most important nutrients, and combinations, are yet to be determined.

### Flavonoids

Flavonoids are found in fruits, vegetables and beverages such as cocoa, dark chocolate, coffee, green tea, and red wine. Resveratrol is a flavonoid that reduced NIHL in rats (Seidman et al. 2003); resveratrol is found in grape skin and red wine. Scotch whiskey (Koga et al. 2007) and beer hops (Magalhaes et al. 2009) have even greater antioxidant capacity than resveratrol; increases in human plasma antioxidant content after beer are more robust than after wine or whiskey (table 4 in review by Lotito & Frei 2006). However, the potential for health benefits with flavonoids in alcoholic drinks is limited for obvious reasons. Supplements that extract and concentrate the active agents are a more viable option, but efficacy must be established in human clinical trials, and dosing must be optimized. Ferulic acid is another flavonoid that reduces NIHL (Fetoni et al. 2010; 2011). The mechanism of protection of flavonoids is an open question. Robust antioxidant activity has been detected *in vitro*, but flavonoids are poorly absorbed and most of what does get absorbed into the blood stream is rapidly metabolized and excreted (for reviews: Manach et al. 2005; Lotito & Frei 2006). Flavonoid intake increases production of urate (uric acid), which is a potent antioxidant, which may contribute to protection after flavonoid consumption (for review: Lotito & Frei 2006).

### Protein

Decreased protein intake increases vulnerability to NIHL (Ohinata et al. 2000), gentamicin (Lautermann et al. 1995a), and cisplatin (Lautermann et al. 1995b). This is not surprising: glutathione production depends on essential amino acids obtained from protein, including glutamic acid, glycine and cysteine. Good sources of protein include poultry, fish, cheese, pork, and beef, followed by milk and yogurt (US Department of Agriculture 2010). When specific amino acids are supplemented, protection against insult is obtained. D-methionine is an amino acid that shows promise as an otoprotective agent (for reviews: Campbell et al. 2007; Campbell & Le Prell 2011; see also ICBEN 2011 paper by Campbell). Another amino acid in protein that has been of interest for protection of the inner ear is cysteine, specifically delivered as N-acetylcysteine (NAC) (for review: Kopke et al. 2007; see also ICBEN 2011 paper by Campbell).

### Carbohydrates

Increased risk for hearing loss in adults has been reported for adults with higher glycemic index (carbohydrate quality metric) and glycemic load (metric incorporating both quality and quantify), as well as total carbohydrate intake (Gopinath et al. 2010a). It was not clear if risk was driven more by glycemic index, glycemic load, or total carbohydrate intake. In contrast, Spankovich et al. (2011) reported that higher carbohydrate intake was significantly associated with increased transient evoked o-toacoustic emission (TEOAE) amplitude, although carbohydrate intake accounted for only 8 % of the variance (Spankovich et al. 2011).

### Fat

Increased dietary fat intake appears to contribute to both cardiovascular disease and hearing loss. After measuring significantly better than expected cardiovascular function and auditory sensitivity in members of the Mabaan tribe of Sudan (Rosen & Olin 1965), Rosen et al. (1970) confirmed a role for dietary fat intake. They manipulated fat intake among patients in two mental institutions in Finland, moving one group off the normal high-fat diet onto a lower-fat experimental diet. Serum cholesterol was significantly lower and hearing thresholds were significantly better in the patients on the low-fat diet after 5 years (Rosen et al. 1970). The diets were then switched at the two institutions; the differences in both serum cholesterol and hearing thresholds were eliminated 3.5 years later, with those on the high-fat diet having worse outcomes than before, and those on the low-fat diet having better outcomes than before (Rosen et al. 1970). Not all fats are equally harmful. Recently, polyunsaturated fatty acids, such as omega-3, were reported to be associated with reduced risk of ARHL in humans (Dullemeijer et al. 2010; Gopinath et al. 2010b). Consistent with this, Spankovich et al. (2011) reported that higher fat intake was significantly associated with poorer TEOAE amplitudes, with fat intake accounting for 8 % of the variance.

### Cholesterol

Cholesterol, which circulates in the bloodstream as solid, waxy, fat, is produced endogenously, and it is obtained via diet. Dietary cholesterol increases both low-density lipoproteins (LDL, “bad” cholesterol) and high-density lipoproteins (HDL, “good” cholesterol). LDL and HDL differentially effect cardiovascular health (Institute of Medicine 2005), and perhaps hearing health as well. HDL appears to be beneficial, as deficient HDL levels were associated with increased human hearing loss, although there was no relationship between total cholesterol and hearing loss in that study (Suzuki et al. 2000). High total cholesterol levels have had inconsistent effects across studies. Although Jones & Davis (2000) reported better hearing thresholds in patients with elevated cholesterol levels, Spankovich et al. (2011) reported worse hearing thresholds in subjects that had higher dietary cholesterol. Cholesterol intake accounted for 8 % of the variance in TEOAE amplitude, 30 % of the variance in high frequency PTA (3,000-8,000 Hz), and 21 % of the variance in low frequency PTA (250-2,000 Hz). In some animal models, high cholesterol diets increase the risk for ototoxicity (Pillsbury 1986; Gratton & Wright 1992); however, in guinea pigs fed a high-fat diet for 14 weeks, both body weight and total cholesterol increased, but there was no meaningful change in otoacoustic emission amplitude (Evans et al. 2006).

### Caloric intake

Caloric intake is relevant to any discussion of diet and hearing. Data from animal models suggests caloric intake influences susceptibility to ARHL (for recent review: Bielefeld et al. 2010). In brief, experimental animals placed on calorie-restricted (CR) diets (e.g. 25-30 % reduction) have better auditory function and/or improved hair cell survival compared to animals maintained on a standard laboratory diet during aging (for examples: Seidman 2000; Someya et al. 2007, 2010).

## CONCLUSIONS

This review focused on the potential impact of dietary choice on hearing health. In most cases, there is minimal data on specific nutrient intake and impact on hearing and/or hearing loss. The specific interaction between dietary intake and vulnerability to noise is difficult to precisely identify given the complex interactions between diet and vascular health, neural integrity, and biochemical free radical balance, as well as interactions with individual genetics, general health (including medications), and other lifestyle factors. The general conclusions across studies are nonetheless clear. A diet that meets all of the vitamin and mineral recommendations, is low in saturated fats and which contains adequate fiber, is highly recommended. Some higher level supplements may ultimately be shown to be useful for protecting the ear against noise, drugs, or age-related decline, but randomized, placebo-controlled studies are critical to any specific recommendations for supplements.

Clinical studies are underway with several supplements. For example, we are measuring the efficacy of ß-carotene, vitamins C and E, and magnesium, in NCT00808470. D-methionine is being evaluated in NCT01345474. The University of Michigan holds the intellectual property (IP) rights to ß-carotene, vitamins C and E, and magnesium (Miller et al. 2010)[1] and the IP rights to D-methionine are held by Southern Illinois University School of Medicine (Campbell 2001, 2008). The IP rights to ebselen are held by Sound Pharmaceuticals (Kil & Lynch 2010), and clinical trials with that agent are also proposed to be conducted by our team, pending funding. For all of these agents, it will be critical to study dose relationships as many antioxidants have the potential to become pro-oxidants when delivered at high levels (Viña et al. 2007).

NIHL is a compelling occupational problem (for review: May 2000). It is a problem for the military, with tinnitus and hearing loss being the two most prevalent service-connected disabilities for US veterans receiving compensation in fiscal year 2009 (US Department of Veterans Affairs 2010). Finally, a third population worth special note is adolescents and young adults. An increasing prevalence of NIHL in children was suggested given some 12.5 % of US children with notched audiogram configurations (based on a sample of 5249 children, ages 6 to 19 years old, Niskar et al. 2001). There has been significant discussion of whether digital audio player (DAP) devices are potentially hazardous to hearing health. That DAP’s can produce harmful sounds levels is clear, but, the extent to which listeners use these devices at levels and durations that can induce hearing loss, and the prevalence of DAP-induced hearing losses in young people as a group, remains under debate (for discussion: editorial comments in Fligor 2006, 2009; Rabinowitz 2010). Male listeners may choose higher listening levels than female listeners (Rice et al. 1987; Williams 2005; Fligor & Ives 2006; Torre 2008; Vogel et al. 2009), and effects of DAP were more evident in males than in females in one recent study (Le Prell et al. 2011c). Taken together, there are multiple populations in need of novel nutraceutical and/or pharmaceutical strategies for protection, and while there is good reason to be encouraged, there is a need for significant additional clinical testing. Until there is clinical data supporting supplement-based strategies, a nutritionally complete, low- saturated fat diet is the best suggestion.

[1] Colleen Le Prell is a co-inventor on U.S. Patent 7,951,845. She previously worked as a paid consultant to OtoMedicine, Inc., and she now serves as the Lead Scientific Advisor for Hearing Health Sciences.

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# Oral pharmacologic otoprotective agents to prevent Noise-Induced Hearing Loss (NIHL): When dietary concentration isn't enough

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## "DRUGS" VERSUS "NUTRACEUTICALS"

A number of oral pharmacologic protective agents for noise-induced hearing loss are in or approaching clinical trials. The demarcation between a nutraceutical and a drug is not always clear. Broadly, the definition of a drug includes "any chemical substance that affects living processes in a positive or negative manner". However that definition is not the legal or regulatory definition. While each country has its own approval processes, the general approach is frequently similar to that in the United States. In the United States, a molecule or compound is classified as a drug if it is "used to treat or prevent a medical disorder". As a drug, these pharmacologic agents are subject to the Pure Food and Drug act of 1906 requiring a list of ingredients, standards for preparation, registration of dangerous or addictive drugs, and prohibition of false or misleading claims. The Sherley Amendment of 1912 prohibited fraudulent therapeutic claims for patent medications, and the 1938 Federal Food, Drug and Cosmetic Act mandated that drugs could not be sold until they had been tested for safety and all labeling was accurate and complete. In 1951, The Durham Humphrey Amendment specified how drugs could be ordered and dispensed and for the first time limited new drugs to investigational use only. Further, for the first time, a separate category for over the counter (OTC) drugs was specifically created. The OTC classification is designated primarily on the basis of safety. Essentially, OTC drugs are deemed sufficiently safe that they do not need direct medical supervision and can be sold directly to the patient without physician direction. For some drugs both prescription and OTC forms are available with the distinction frequently being in dosing or method of administration. For a review the reader is referred to (Meldrum 2007) Thus agents classified as "drugs" must meet the following standards:

1) The ingredients must be listed.

2) They must meet standards for preparation.

3) They may not make false or misleading claims, including false therapeutic claims.

4) They must be tested for safety.

5) All labeling must be accurate and complete.

6) They are subject to laws regulating how they can be ordered and dispensed.

7) New drugs are limited to investigational use only and cannot be sold until approved by the Food and Drug Administration (FDA).

8) The FDA approval specifies whether the drug is available by prescription only or can also be sold OTC and if so at which dose and in which specific formulation.

The FDA approval is extensive. Current estimates are that, on the average, it takes a drug approximately 15 years and over 1 billion US dollars to go from bench to bedside including FDA approval for marketing.

Thus while expensive and time consuming, an agent classified and FDA approved as a drug affords the consumer many protections and assurances.

Nutraceuticals and dietary supplements are not subject to the same regulations as drugs even though some may have some of the same ingredients as "drugs". Nutraceuticals may be advertised with the disclaimer "not intended to diagnose, prevent, cure, or treat any medical disorder" to avoid being classified as a drug. Frequently they are labeled "to promote hearing health" or similar language. Nutraceuticals fall under the Dietary Supplement Health and Education Act (DSHEA) of 1994. The FDA does have the authority to limit claims under DSHEA regarding therapeutic efficacy and labeling but because they are classified as "foods" many, if not most, are not reviewed by the FDA. As foods, they do not have to prove safety or efficacy. Herbal medications are also classified as dietary supplements and thus no testing for safety or efficacy is required. Because the distinction between drug and nutraceutical can be complex, for some agents manufacturers may seek, or be required to seek, an FDA exemption to ensure that the FDA does not consider it to be a drug, subject to the above listed regulations. Sometimes an exemption can be granted on the basis of the compound's known safety but an exemption does not guarantee efficacy or allow it to be marketed as a drug.

For drugs, the FDA approval process requires that the potential side effects and drug interactions be listed. Although nutraceuticals, dietary and herbal supplements, and even foods themselves, may also have side effects and adverse drug interactions with the patients' other medications, no testing, listing or specification of them is required.

Complementary and integrative medicine, which includes nutraceuticals is gaining much more widespread acceptance in Westernized countries but the consumer should be aware, that while they may be very effective in some cases, they do not carry the same degree of regulation and assurances (see reviews by Seidman & Moneysmith 2007; Meldrum 2007). However because they are not subject to the expensive FDA approval process, they have the potential to be less expensive and progress more quickly to the marketplace.

Interestingly, all the oral "drugs" in or approaching clinical trials to prevent noise-induced hearing loss are antioxidants, also present in foodstuffs. However they may be classified as a drug on the basis of the claims being made to prevent or treat noise-induced hearing loss, or on the basis of containing concentrations above the usual levels of diet or dietary supplements. Companies may seek FDA approval so that they may market the compound with the specific claims and safety assurances that approval allows.

This review is restricted to compounds that can be given orally. While some agents are being developed that cannot be safely administered systemically and can only be given via round window administration, their clinical acceptance to routinely prevent or rescue from noise-induced hearing loss is probably limited. The costs and risks of repeated round window drug administration could also be problematic for noise-induced hearing loss. Further patient acceptance and compliance are always major factors for any medical treatment.

Antioxidants that are present in foodstuffs have a number of advantages. Frequently as a component of food, their bioavailability, absorption, and distribution through the gastric pathway are known. Usually their safety profile including safety ranges, and effects of high dosing over long periods of time in a number of species have already been studied, in some cases for decades in both human and animal nutrition studies.

Interactions with other drugs or in specific patient populations such as pediatric or geriatric populations are also frequently known.

Although all of the following agents are antioxidants, they do not all have the exact same mechanisms. The general classification of antioxidant indicates that the agent either directly donates an electron (direct antioxidant) or facilitates other compounds (e.g. glutathione) donating an electron (indirect antioxidant) to the unpaired electrons of the outer shell of free radicals, thus stabilizing it. Some agents are both direct and indirect antioxidants. For many agents, the mechanisms of protection are still being elucidated.

The antioxidants that are currently in or approaching clinical trials through the FDA clinical trials and approval process, to prevent noise-induced hearing loss include D-methionine (D-met), ebselen, and N-acetylcysteine. All of these agents can be delivered orally.

D-MET

**Clinical trials**

D-met is approaching clinical trials with the US Army to prevent noise-induced hearing loss in drill sergeant instructor trainees during their required M-16 weapons training. These clinical trials are funded through a grant from the US Department of Defense. Although D-met can be effectively delivered through the round window (Korver et al. 2002; Wimmer et al. 2004) and by injection (Campbell et al. 1996; Kopke et al. 2002; Sha & Schacht 2000) for various applications, for clinical trials the current formulation is an orange flavored oral suspension with flavor matched placebo (Hamstra et al. 2010) which has been prepared according to the FDA Good Manufacturing Practices (GMP) standards. A Phase 1 manuscript has been published (Hamstra et al. 2010) and 2 small scale Phase 2 clinical trials were conducted in India demonstrating protection from radiation induced oral mucositis (in preparation for publication) and from cisplatin-induced hearing loss (Campbell et al. 2009). The preparation is stable for at least 18 months at 40 degrees centigrade, which can be particularly useful for military settings. A human dose is approximately a teaspoonful depending on subject weight.

Although D-met is a component of fermented proteins such as cheese and yogurt, the clinical trials are going through the FDA approval process.

**Protection in animal studies**

Animal studies using prophylactic D-met administration in chinchillas (Kopke et al. 2002; Campbell et al. 2007), mice (Samson et al. 2008) and guinea pigs (Cheng et al. 2008) have been conducted in a variety of laboratories confirming virtually complete protection from permanent noise-induced hearing loss cochlear outer hair cell loss at least for the noise exposures used in those studies (Cheng et al. 2008), Campbell et al. 2009). Protection from permanent threshold shift has been consistent across studies (Kopke et al. 2002; Campbell et al. 2007; Cheng et al. 2008; Samson et al. 2008). No studies have shown a lack of protection or exacerbation of noise-induced hearing loss.

However, protection from hearing threshold shift within the first 24 hours after noise exposure has produced variable results across studies. Cheng et al. (2008) reported virtually complete D-met protection from noise-induced threshold shift 24 hours after noise exposure in guinea pigs after a 10 minute 105 dB noise exposure and again after 7 days. However Kopke et al. 2002 reported no significant D-met protection 24 hours after noise exposure in chinchillas after a 6 hour 105 dB SPL noise exposure although D-met provided virtually complete protection from permanent threshold shift 21 days after noise exposure in those same animals. Samson et al. (2008) reported no significant D-met protection 24 hours after noise exposure but with complete protection from permanent noise-induced threshold shift both at 14 and 21 days after a 4 hour 110 dB noise exposure. It would appear that protection from threshold shift 24 hours after noise exposure may vary by species and type of noise exposure while protection from permanent threshold shift occurs irrespective of species, at least in studies reported to date. Dosing protocols have also varied. Cheng administered 300 mg/kg D-met to guinea pigs one hour before and one hour after the noise exposure. Samson et al. (2008) also delivered the D-met one hour prior to and one hour after noise exposure but used 400 mg/kg in mice. Kopke et al. (2002), used a lower dose but for a longer time period in chinchillas, administering 200 mg/kg D-met twice per day starting 2 days prior to noise exposure and continuing 2 days after noise exposure. Campbell et al. (2007) also reported almost complete rescue from permanent threshold shift first administering D-met one hour after a 6 hour 105 dB SPL noise exposure and then continuing twice per day for another 2 days. Further first administration of D-met can be delayed for up to 7 hours after noise exposure and still provide significant protection from outer hair cell loss and permanent threshold shift (Campbell et al. 2009). Thus it appears that D-met protection and rescue from permanent noise-induced hearing loss is consistent across noise exposures used thus far, across a variety of species, and for a wide range of dosing protocols. However protection from noise-induced threshold shift at 24 hours may vary by species, noise exposure or dosing protocol.

Multiple animal studies have also documented D-met's efficacy as a protective agent against cisplatin-induced hearing loss (Campbell et al. 1996, 1998) aminoglycoside-induced hearing loss (Sha & Schacht 2000) and radiation induced oral mucositis (Vuyyuri et al. 2008). Because some patients are exposed to one or more of these in addition to noise-exposure, an agent that is cross-protective may be advantageous for some patients.

EBSELEN

## Clinical trials

Sound Pharmaceuticals is planning Phase 2 clinical trials at Camp Pendleton, San Diego, California for protection from noise-induced hearing loss in Marines undergoing their artillery training. Phase 2 clinical trials for protection from temporary threshold shift in humans are also in the planning stages. Ebselen, a selenium based compound, is currently formulated for oral administration, according to FDA GMP standards, as a dry blend capsule with matched placebo. In addition they are planning clinical trials in Seattle to protect against cisplatin-induced hearing loss. No clinical trials have yet initiated for either application but they are going through the FDA approval process for them.

### Protection in animal studies

Studies in both rats and guinea pigs have consistently shown either partial or complete protection from permanent noise-induced hearing loss (Pourbakht & Yamasoba 2003; Yamasoba et al. 2003, 2005; Lynch et al. 2004; Lynch & Kil 2005; Kil et al. 2007). As for D-met, no study has reported a lack of protection or exacerbation of noise-induced hearing loss. Significant reduction in temporary threshold shift 3 hours after noise exposure in guinea pigs has been reported (Yamasoba et al. 2005) but no other study has reported findings for temporary threshold shift with ebselen.

For permanent noise-induced threshold shift, ebselen provided incomplete but significant protection from a 4 hour, 110, 113 or 115 dB SPL, 4-16 kHz noise band noise exposures in rats. (Lynch et al. 2004; Lynch & Kil 2005; Kil et al. 2007). In guinea pigs, significant protection from permanent noise-induced threshold shift was also reported after a 5 hour 125 dB SPL 4 kHz octave band noise exposure.

N-ACETLYCYSTEINE (NAC)

### Clinical trials

NAC has been long studied as a putative agent to protect against noise-induced hearing loss. However in 4 clinical trials conducted to date, none have shown significant protection from either temporary or permanent noise-induced hearing loss (Toppila et al. 2002; Kramer et al. 2006; Balough 2011). Topilla et al. (2002), using 400 mg NAC per day, and Kramer et al. (2006) using 900 mg NAC per day and tested subjects hearing before and after exposure to night club noise. Neither study showed significant NAC protection. At Camp Pendleton two prospective, randomized placebo controlled clinical trials were conducted (Balough 2011) in Marine recruits during either 2 weeks or 16 days of weapons training. Either 900 mg of NAC or placebo was administered 3 times per day starting 2 days before weapons training and continuing 3 days after weapons training (study 1) or 2 grams of NAC twice per day (study 2). Final hearing tests were conducted 2 weeks (study1) or 10 days (study 2) after cessation of weapons training. The only side effect was excessive flatulence, possibly secondary to the fizzy tab formulation of their oral preparation. They concluded that although their clinical trials site using the Marine recruit population was optimal for testing otoprotective agents, NAC was not an effective otoprotective agent for noise-induced hearing loss even at the 4g/day dose of study 2 which is the upper level of feasibility for NAC oral delivery due to drug compounding considerations. Reportedly, the Department of Defense does not plan further testing for NAC as an otoprotective agent for noise-induced hearing loss.

### Animal studies

Although NAC is one of the most widely studied agents for protection from noise-induced hearing loss, results across studies are not in agreement. Although some studies have shown at least partial protection from noise-induced hearing loss (Ohinata et al. 2003; Bielefeld et al. 2007; Lorito et al. 2008; Fetoni et al. 2009) other studies have demonstrated no protection (Hamernik et al. 2008) or even exacerbation of noise-induced hearing loss (Duan et al. 2004). In some cases, protection from noise-induced hearing loss attributed to NAC may have been secondary partially or completely to a concomitant agent. (Huang et al. 2000; Kopke et al. 2002, Liu et al. 2001), reported NAC protection from NIHL but only when combined with high dose salicylate, which in itself is otoprotective (Yu et al. 1999). Clinically high dose aspirin is unlikely to gain clinical acceptance as an otoprotective agent because it cannot be safely used in children and because the required high doses may have gastrointestinal toxicities or exacerbate other bleeding. Although NAC alone has shown some otoprotection from noise-induced hearing loss in some animal studies (Kopke et al. 2005, 2007) with the negative results from clinical trials to date, it does not appear to be among the most promising agents to prevent or rescue from noise-induced hearing loss.

## SUMMARY

In summary, several agents are going through the FDA approval process for clinical trials to prevent noise-induced hearing loss. Currently D-met and ebselen are in or approaching FDA approved clinical trials. They both have an extensive body of consistently positive animal data supporting their development. Hopefully one or more agents will be FDA approved for use in the next few years. As discussed in Dr. LePrell's paper, a number of nutraceuticals also show excellent promise. While nutraceuticals do not generally go through the FDA approval process, some compounds like ACE Mg are promising and are undergoing rigorous clinical trials to also ensure safety and efficacy. In the future the incidence and severity of noise-induced hearing loss may be reduced.

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# Contribution of genetic factors to noise-induced hearing loss

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ABSTRACT

Individual susceptibility to noise-induced hearing loss (NIHL) differs remarkably among individuals and depends on genetic and environmental factors. The genetic basis of NIHL has been documented in animals. Mouse strains exhibiting age-related hearing loss were shown to be more susceptible to noise than other strains, while some knock-out mice, such as SOD-/-, PMCA2-/- and CDH23+/- were more sensitive to noise than their wild-type littermates.

Recently, the first association studies that aimed at identifying gene polymorphisms contributing to NIHL in man were performed. The most interesting candidate susceptibility genes include oxidative stress genes, $K^+$-recycling pathway genes and heat shock proteins genes. Significant associations between KCNQ4, KCNE1 and CAT gene polymorphisms and susceptibility to NIHL have been shown in two independent European populations (Swedish and Polish). HSP70 polymorphism was significantly associated with NIHL susceptibility not only in these two European populations, but also among Chinese workers. More research with using high-throughput genotyping methods is needed to confirm whether their polymorphisms truly determine inner ear vulnerability related to noise exposure. The interactions between genetic and environmental factors will be discussed.

# Summary of evidence of risk for noise-induced hearing loss from recreational music exposures: prevalence estimates and potential severity of threshold shift and other hearing disorders

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REVIEW

Hearing loss from the abusive use of portable listening devices (PLD), such as the Apple iPod®, other digital music players, compact disc players, etc., is a controversial topic, drawing intense interest from popular media outlets and appropriate criticism from some in the scientific community. There is sparse evidence that headphones cause hearing loss, with only a few papers reporting such findings just emerging. The quality of published data is suspect in some instances, and overstatement of the risk for hearing loss from using headphones validates the skeptics. While the magnitude of the problem and percent of people affected is a matter of debate, it is clear there is risk for hearing loss from using PLD inappropriately. This paper will summarize what is understood about risk for noise-induced hearing loss (NIHL) from using PLD, propose a mental framework for size and magnitude of the potential problem, and offer future direction for research.

Of all the causes of sensorineural hearing loss, noise is arguably one of the most common, and most preventable. NIHL is reported to be the 2nd most common etiology of sensorineural hearing, with presbycusis being the most common (Royster 1996). It has been argued that some forms of age-related hearing loss (sensory presbycusis, for instance) reflect a lifetime of wear-and-tear, and so cumulative noise exposure shoulders a considerable portion of the contribution for presbycusis. The National Institutes of Health (NIH) in the United States reported at a consensus conference on noise-induced hearing loss in 1990 that noise exposure is at least partially responsible for roughly one-third of all sensorineural hearing loss in the United States (NIH 1990). How much hearing loss is from occupational exposures and how much can be attributed to recreational exposures is debatable.

## Fundamental understanding of sound exposure from headphones

Necessary to understanding the topic of “headphones and hearing loss” is an understanding of the acoustics of sound presented in the “near field” of the ear (where the head, ear, and ear canal have a marked effect on the level measured) compared to sound presented in the “free field” (where the head, ear, and ear canal are not considered in the measurement of the potentially offending sound). Also, it is helpful for the reader to have a general understanding of masking of a desired signal by an unwanted signal, and how active noise cancellation and passive sound isolation provided by some earphones can influence the level of ambient sound masking the music from earphones.

The data sets used to determine the degree of hearing loss caused by noise were collected in the late 1960’s and early 1970’s in predominantly white, adult male populations that were exposed to industrial noise (Passchier-Vermeer 1968; Burns & Robinson 1970; Baughn 1973; Lempert & Henderson 1973). These data were instrumental in developing standards (International Organisation for Standardisation, ISO

1999 (1990); American National Standards Institute, ANSI S3.44 (1996)) to describe the relationship between noise exposure and noise-induced permanent threshold shift (NIPTS) and regulations (Occupation Safety and Health Administration, OSHA (1983)) and safety recommendations (National Institute for Occupational Safety and Health, NIOSH (1998)). Current understanding from these data is that a maximum exposure of 85 dB, A-weighted (dBA), for an 8-hour daily exposure over a working lifetime of 40 years results in roughly 8 % of exposed persons having a hearing handicap (Prince et al. 1997), owing to the wide variability seen in susceptibility to NIHL across individuals. Due to promulgation of regulations in the economically developed countries since these data were collected, it is now all but impossible to obtain a "clean" data set of noise-exposed workers. As a result, new understanding of the effect of noise on the hearing of the general population involves reanalysis of these existing data sets, rather than collecting original data across a more diverse population. Extrapolation of estimates of NIPTS to other populations (such as children and adolescents) exposed to non-industrial sound exposures (such as music) is therefore tenuous.

Limitations acknowledged, it is well understood that a higher sound level results in equal risk for NIHL in a shorter time than a lower level sound, above a maximum "safe" level known to not contribute to NIHL (Melnik 1991). Most developed western countries limit worker exposure to 85 dBA, 8-hr TWA using the 3-dB exchange rate. When considering recreational exposures, it is necessary to remember from the damage-risk associated with both 90 dBA, 8-hr TWA and 85 dBA, 8-hr TWA, regardless of exchange rate, does not prevent hearing loss. These criteria seek to limit risk for hearing loss to an "acceptable" level, which is a trade-off between scientific data and economic factors. Efforts to prevent *all* auditory injury from sound exposure should consider the trade-off between scientific evidence and recommendations that might be too strict for followers to appreciate the benefit, and stay motivated to moderate music-listening behavior.

The data used to develop existing DRC were collected using sound level meters, measuring ambient noise in the free field of the workers' environment. Hearing hazard was thus defined by sound in the free field. It has been reported that if dosimetry had been conducted using probe-microphones at the workers' eardrums, this could account for a considerable amount of variability seen in the degree and prevalence of hearing loss from equal free field sound exposures (Shotland 1996), owing to differences in the resonance of the external ear across individuals. Earphones are coupled to the ear, and cannot be measured using standard ambient sound-sampling sound level meters. Levels from earphones must be measured either with a microphone in the real ear (MIRE technique) or using a coupler; these recorded levels are meaningless to DRC, however, without applying transfer functions to convert levels to free-field equivalent (ISO 11904-1 (2002); ISO 11904-2 (2004)). Such conversions are necessary to account for the acoustics of the ear and presentation of sound in the "near field" using earphones, rather than in the free field.

Hearing healthcare professionals have intimate familiarity with the concept of masking, as the introduction of sound to elevate the detection threshold (most often of the non-test ear) is fundamental to performing audiometry. Studies of speech intelligibility often report a performance-intensity function, indicating better speech-intelligibility with improved signal-to-noise ratio. It is no surprise, then, that when listening to music in background noise, a person might increase the music level when background noise increases. Some manufacturers of consumer electronics headphones and earphones see the potential for value-added features, and have introduced technology to mitigate the effects of masking from ambient sound.

### Output levels from earlier technology

Early studies investigating hearing loss risk from cassette players reported maximum output levels of 124 dBA (Wood & Lipscomb 1972) and 110-128 dBA (Katz et al. 1982). The reported output of the cassette players in the Katz et al. (1982) study exceeded 85 dBA at 30 % of the volume control. Both studies reported levels measured in a coupler, without converting to free-field equivalent levels, so the reported levels cannot be compared to DRC. Turunen-Rise et al. (1991) reported maximum free-field equivalent sound levels from cassette players of 98-108 dBA and from compact disc players of 98-110 dBA. Further, six subjects in the Turunen-Rise et al., study exhibited a temporary threshold shift (TTS) after listening to music at 80 % of the maximum volume setting on cassette player for one hour. Although one might consider these results to suggest using headphones in such a manner poses a risk to the user's hearing, the authors interpreted their findings conservatively; they concluded there was little risk for permanent hearing loss. Their conclusion was drawn from the fact the median TTS was 12 dB (not considered a large shift), and the six subjects (seated in a quiet laboratory) reported 80 % volume control setting was higher than they would have preferred.

Fligor & Cox (2004) reported the output levels from commercially available CD players and after-market accessory headphones. A few headphone-CD player combinations achieved sound levels exceeding 120 dBA free-field equivalent, and peak sound pressure levels above 130 dB SPL, depending on music genre. The highest-selling CD player, the Sony CD Walkman, produced 87 dBA with the volume control set to half-maximum, and 107 dBA at maximum, using the on-the-ear earphones that were included in the purchase of the device. Using an 85 dBA, 8-hr TWA with 3-dB exchange rate DRC, the authors suggested limiting listening level to 60 % of the maximum volume control if listening for one hour or less per day (this corresponded to a 50 % noise dose, which is half the recommended noise exposure limit). Using after-market accessory earbud earphones could result in 7-9 dB increase in sound level, relative to levels from on-the-ear earphones, so the suggested guideline would need to be modified accordingly if the consumer preferred earbuds.

### Output levels from newer technology

Sales of PLD have increased dramatically since the Apple iPod ® was first introduced in 2001. Sales of all PLD were projected to be 275 million by 2011 (Ethier 2008). The exceedingly high popularity of the newest generation of PLD has fueled some of the popular media coverage, which is beneficial for raising public awareness. Given the lack of peer review, claims made by any reporter ought to be viewed with skepticism, even if the story references studies published in peer reviewed academic literature. At the same time, readers of stories on "iPods and hearing loss" should give benefit of doubt to researchers quoted in the press. The press has a product to sell, and hyperbole sells. Qualified statements given in interviews are often shortened for space and time constraints, and some claims that seem outrageous from a scientist are in fact out of context without the statement qualification.

Williams (2005) investigated chosen listening levels in passers-by on a busy city street in urban Australia. Although the focus of that study was not to determine sound levels from portable digital music players, it can be surmised from the results that levels from portable digital music players exceeded 100 dBA free-field equivalent. Ahmed et al. (2006) reported levels from the Apple iPod ® earbud earphones depended on the music genre and graphic equalizer setting, but at maximum volume control, free-field equivalent sound levels approached 100 dBA. French law mandates a maximum level of “100 dB” from personal stereo systems with headphones and specifies a maximum output voltage to headphones not exceed 150 millivolts (Legifrance 2005). It is unclear whether or not different PLDs are manufactured for sale in Europe than the rest of the world. Of additional concern to this author is that this maximum level mandate is certainly not safe. According to the 85 dBA, 8-hr TWA, 3-dB exchange rate DRC, a PLD meeting the requirements of French law will exceed recommended exposure limits after 15 minutes of use at the maximum “limited” level. Some PLD, such as the iPod ®, have a volume control limiter in the software controlling the device, and include a password to lock this maximum limit. A limitation of this software is that no guidance is provided to the user what levels to limit, and considers only level, not duration of use.

Portnuff et al. (2011) reporting findings in good in good agreement with those of Williams (2005) and Ahmed et al. (2006). Further, similar to the goals of Fligor & Cox (2004), a rough “acoustic speed limit” for using headphones in a manner that reduces risk for NIHL, volume control should be limited to 80 % of maximum if listening duration is 90 minutes or less per day, using earphones that are purchased with the digital PLD.

**Patterns of usage and potential risk for NIHL**

Some research has attempted to link qualitative descriptors of loudness to PLD users’ actual listening levels. Torre (2008) reported that 35 % of over 1,000 university students surveyed listened at a “loud” level, while 6 % listened at a “very loud” level. A smaller set of listeners (n=32) were asked to choose listening levels in the laboratory, corresponding with their judgment of “loud” and “very loud” while measures were made at the eardrum using a probe microphone. The actual sound levels indicated that a “loud” level corresponded to a mean of 87.7 dB SPL, while “very loud” corresponded to a mean of 97.8 dB SPL. A limitation of this data set, however, is that these levels were reported in dB SPL (not A-weighted), and were not converted to free-field equivalent (ISO 11904-1 2002). Both the levels associated with the “very loud” and “loud” descriptors had large standard deviations (5-9 dB), indicating that the actual levels corresponding to listeners subjective descriptions of loudness varied considerably.

Often, ambient environmental noise cannot be easily controlled by the individual; if the individual is listening to music via headphones, high level ambient noise should induce the headphone user to increase the volume control. Airo et al. (1996) reported chosen listening levels to headphones in quiet and in noisy environments. Mean free-field equivalent chosen listening level in quiet was 69 dBA, with 15 % of subjects choosing levels in excess of 85 dBA. The mean chosen listening level was raised to 85 dBA when the background noise reached 72 dBA. In quiet environments, the majority (but not all) chose to listen at levels well below 85 dBA. When the noise level in the ambient environment began to interfere with music listening, subjects increased the volume, seeking on average a signal-to-noise ratio of +13 dB.

Williams (2005) surveyed the listening levels of 55 passers-by in Melbourne and Sydney, Australia, outside of busy public transportation hubs. The average ambient noise level was 73.2 dBA, and the average listening level was 86.1 dBA. Thus, as with the Airo et al. (1996) study, an average chosen signal-to-noise ratio of +13 dB was observed. A wide range was seen in their group, with chosen levels from 73.7 dBA to 110.2 dBA.

Hodgetts et al. (2007) asked a group of 38 young adults with normal hearing to set music on a digital PLD to their preferred listening level using two different headphones: an earbud earphone and over-the-ear earphones with active noise cancellation. Preferred listening level was assessed using a microphone at the eardrum, in “quiet” (level unspecified) and in two different background noises (70 dBA multi-talker babble and a street noise varying 70-80 dBA). The reported chosen listening levels were similar across earphones in quiet (average 76 dBA), and increased with the higher level background noises (average 83.7 dBA in 70 dBA babble; 85.4 dBA in 70-80 dBA street noise). In noise, their subjects chose highest levels using earbuds; next highest levels were chosen with over-the-ear earphones with active noise cancellation off, and lowest levels were chosen with over-the-ear earphones with active noise cancellation on. The authors concluded that people choose higher levels using earbud earphones compared to over-the-ear earphones in background noise. Two limitations of this study confound their conclusions. First, the levels reported were not free-field equivalent, so cannot be compared to DRC. Second, the authors did not account for the attenuation provided by the earphones, beyond describing the effect of the active noise cancellation (reduction in ambient sound below 1,000 Hz). It is possible the over-the-ear earphones were a closed-style, completely surrounding the pinna and providing passive sound isolation as well as active noise cancellation. The attenuation properties of the earbud were not described. It is likely that the differences reported in chosen listening level had to do with the attenuation properties of the earphones, rather than the earphones themselves.

Preliminary findings from a manuscript currently in preparation have been presented describing the effect of ambient background noise as well as the influence of headphone type on chosen listening level (Fligor & Ives 2006). In this study, subjects listened to music in various levels of background noise using earphones that provided varying amounts of passive sound isolation. Average chosen listening level in quiet was roughly 61 dBA across all headphones. As background noise increased, chosen listening level increased in a predictable fashion in those subjects who chose moderate levels in quiet. The majority of subjects chose levels 85 dBA or greater when listening in a simulated airplane cabin (80 dBA background noise) when using earphones that provided no sound isolation (an earbud and a supra-aural headphone that provided little to no sound isolation). Using an in-the-canal earphone that provided considerable passive sound isolation (ER-6i, Etymotic Research, Inc., Elk Grove Village, IL), the number of subjects who chose a listening level of 85 dBA or greater decreased dramatically.

Levey et al. (2011) examined the sound level and duration of use of PLDs by 189 college students, ages 18-53 years, as they entered a New York City college campus to determine whether noise exposure from PLDs was in excess of recommended exposure limits and what factors might influence exposure. Free-field equivalent sound levels from PLD headphones were measured on a mannequin with a calibrated sound level meter. Based on measured free-field equivalent sound levels from PMP headphones and the reported PLD use, per day 58.2 % of participants exceeded 85 dB A-weighted 8-hr equivalent continuous levels ($L_{Aeq}$), and per week 51.9 % exceeded 85 dB A-weighted 40-hr equivalent continuous continuous levels (LAwkn). The majority of PLD users exceeded recommended sound exposure limits, suggesting that they were at increased risk for noise-induced hearing loss.

### Evidence of NIHL from using PLD

Evidence that listening to music via headphones poses a risk to hearing is sparse. As was described earlier, "risk" is a relative term. Interpretation of risk is greatly influenced by whether the goal is prevention of all hearing loss or minimization of the percentage with a hearing handicap. Actual cases of confirmed NIHL from headphone use are few. Meyer-Bisch (1996) conducted high resolution pure-tone audiometry on a huge study population and stratified subjects into those who used personal cassette players (PCPs) longer than 7 hours per week and those who used PCPs 2 to 7 hours per week. A very small, but statistically significant, elevation of pure-tone thresholds was seen in the PCP users who listened for at least 7 hours weekly, compared to those who used a PCP for shorter durations. A limitation of this study was that no attempt was made to assess chosen listening levels, and so actual noise exposure cannot be correlated with the small group-NIPTS.

LePage & Murray (1998) measured transient evoked otoacoustic emissions (TEOAEs) in 1,724 patients, and stratified subjects into four categories: non-noise exposed, exposed to industrial noise only, PLD users with no industrial noise exposure, and PLD users who were also exposed to industrial noise. Relative to the control group (non-noise exposed), TEOAE response was, on average, reduced in both PLD users and in those exposed to industrial noise only, and an additive effect on TEOAE reduction was observed in those exposed to both industrial noise and personal stereo systems. Multiple linear regression modeling showed that "heavy" PLD use had a greater effect on reduction of TEOAE response than did industrial noise exposure.

Recently, studies have suggested early, subtle damage in persons identified as regularly using PLDs compared to those who are not PLD users. Le Prell et al. (2011) found 7 % of subjects self-described as having "normal hearing" had hearing loss of > or = 25 dB HL in at least one frequency. There was a statistically significant relationship between use of PLD and having hearing loss in male subjects. Likewise, Kumar et al. (2009) showed a significant correlation between increased pure-tone thresholds at 6,000 Hz in both ears and estimated 8-hour equivalent exposures from PLD > 80 dBA; likewise, they found decreased DPOAEs in the high frequencies in both ears were correlated with $L_{eq,\ 8h}$ > 80 dBA. Despite the barriers to successfully showing an effect on cochlear function, this study's authors showed a significant correlation between PLD listening behavior and auditory function.

### Noise exposure estimates from PLD

A few studies have estimated noise exposure based on measured chosen listening levels and reported listening duration. Felchlin et al. (1998) reported a mean listening duration of 4 hours per week (range 1 to 21 hours) in 350 users of PCPs. Average listening level was 83 dBA and 40 % chose levels greater than 85 dBA. There was no correlation between cumulative listening duration and chosen listening level. The average estimated noise exposure was 72 dBA, 8-hr TWA, with 10 % estimated to exceed 85 dBA, 8-hr TWA, and 5 % exceeding 87 dBA, 8-hr TWA.

Rice et al. (1987) surveyed headphone listening time in 500 school children (average age 15.7 years) and conducted listening level measurements in a subset of subjects. They estimated that 5 % of subjects in their study would meet or exceed 90 dBA, 8-hr TWA. To consider whether or not such exposure might result in a "hearing disability," Rice, et al., compared their estimates of noise exposure to models for NIPTS prediction. Defining hearing disability as equal to, or greater than, 30 dB HL averaged across 1,000, 2,000, and 3,000 Hz, only 0.065 % would have a hearing disability (1 in 1,538 headphone users). This estimate of a very small percentage of population risk could be misleading. Their definition of hearing disability is very liberal; a "material hearing impairment" as defined by NIOSH (1998) is a weighted average across 1,000, 2,000, 3,000, and 4,000 Hz of 25 dB HL. The current permissible exposure limit promulgated by OSHA (1983) of 90 dBA, 8-hr TWA seeks to limit risk for material hearing impairment to not more than 22 % of the exposed population (Prince et al. 1997). If Rice et al. (1987) had used this definition for hearing disability, a much higher percentage would have been found to be at risk.

The subjects in Williams (2005) were users of digital PLD, which might suggest that longer listening time would be seen (and correspondingly higher TWA), compared to studies of PCP use. Williams (2005) conducted his study in what was considered a "worse-case scenario" where listening levels were obtained in fairly high ambient noise. If measured chosen listening levels were typical, then based on self-reported listening duration, Williams (2005) estimated an average 79.8 dBA, 8-hr TWA in PLD users. Considering that this exposure is below the maximum permissible occupational exposure level of 85 dBA, 8-hr TWA, in Australia, Williams (2005) reported that the average PLD user is not at risk for NIHL from his/her device. He noted, however, that his TWA estimate was above 75 dBA, 8-hr TWA, which was considered the maximum level for negligible NIHL risk. Twenty-four percent of his subjects had an estimated 85 dBA, 8-hr TWA or greater, and 3 % had 100 dBA, 8-hr TWA or greater.

## FUTURE RESEARCH AND IMPLICATIONS

In 2006, a telephone survey of 1,000 adults and 301 adolescents was commissioned by the American Speech-Language Hearing Association that asked about respondents' listening habits using digital PLD (Zogby International 2006). Fifty-two percent of the adults surveyed reported that a typical listening session lasted one to four hours, or longer than four hours, while 31 % of teenagers used PLD for longer than one hour during a typical listening session. However, when asked to subjectively report the level at which they used their PLD, teenagers were more likely to play their music at a "somewhat loud" or "very loud" setting (59 % of respondents) compared to adults (34 % of respondents). Teenagers, then, appear to use their devices at higher levels than adults, though possibly for shorter durations. However, there is a paucity of peer-reviewed literature that can verify whether teenagers actually listen at higher levels (Portnuff et al. 2011). Research being conducted by this author and his colleague, Dr. Cory Portnuff, seeks to characterize adolescent use of PLD and explain their listening levels based on ambient listening environment, earphone sound isolation, and knowledge, attitudes, and beliefs toward NIHL as described by the Health Belief Model (Rosenstock 1960). The Health Belief Model provides a model with several generic constructs that can be adapted to explain the beliefs behind specific health behaviors. Perhaps if specific factors can be identified that separate "loud music listeners" from the rest of the population, targeted education and intervention can be provided to those most at risk for NIHL.

As noted earlier, projected sales of PLD were 275 million by 2011 (Ethier 2008); of 2,408 respondents to this 2008 survey, 52 % owned a PLD. Even by the Rice et al. (1987) liberal definition of hearing disability (30 dB HL or greater averaged 1,000 – 3,000 Hz), with their estimated 0.065 % "at risk," this would suggest that 178,750 PLD users would have significant hearing loss from this noise source alone. Another way to consider the impact of this preventable hearing loss is to consider the lifetime contribution of wear-and-tear on the ear. Figure 1 shows the hearing thresholds, as a function of frequency, of the average adult male aged 30 to 60 years, from the ANSI S3.44 (1996) unscreened population (Annex B). Shown in Figure 2 is the NIPTS predicted by ANSI S3.44 (1996) for a person using a PLD at 90 % of the maximum volume control (Portnuff et al. 2011) for 2 hours per day, for 10 years. Shown in Figure 3 is the NIPTS prediction for 4 hours PLD use per day at 90 % of maximum volume control, after 10 years. Overlaid on Figures 2 and 3 is the average hearing level of 50- and 60-year-old men as a function of frequency. Based on literature summarized in this manuscript, across telephone surveys, studies of chosen listening level, and output capacity of PLD, it is reasonable to believe that a small, but significant, percentage of PLD users might have the hearing of a 50- to 60-year old man after 10 years of irresponsible listening habits. Consider the 15-year-old who uses his PLD every day on his way to and from school, and while doing homework, and consider that at age 25 years, after completing college, he needs hearing help because he has accelerated the aging of his ears by 30 years. The assignment of responsibility to prevent such unnecessary hearing loss should not fall only to the manufacturer, but to the consumer to seek out professional advice, and to the scientific community to advise both the manufacturer and consumer in better ways to allow responsible use of these wonderful devices.

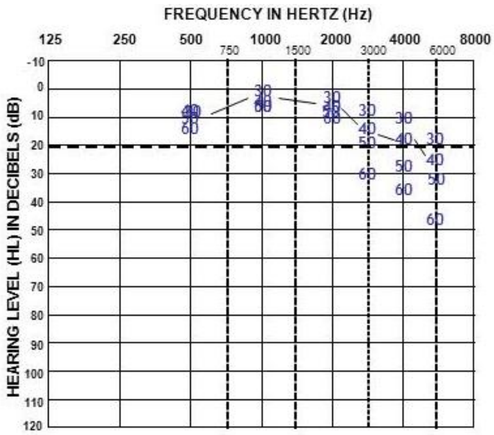


**Figure 1:** Average hearing threshold levels of men aged 30, 40, 50, and 60 years, according to ANSI S3.44 (1996), Annex B (unscreened population)

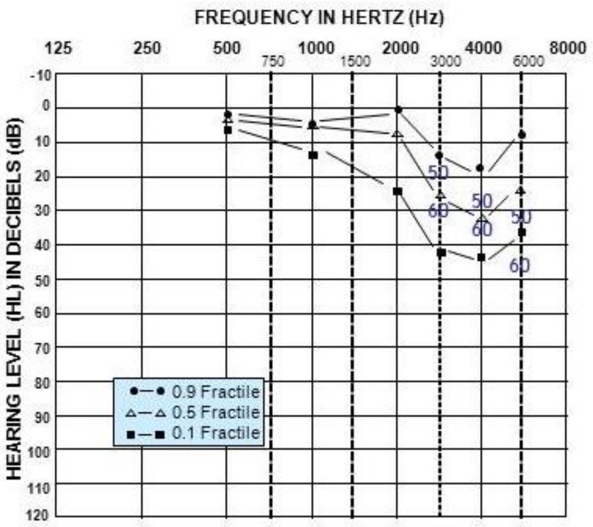


**Figure 2:** NIPTS predicted by ANSI S3.44 (1996) from use of a digital PLD for 2 hours per day, 5 days per week for 10 years at 90 % of the maximum volume control. The symbols “50” and “60” denote average hearing threshold levels for a 50-year-old and 60-year-old man according to ANSI S3.44 (1996), Annex B. Population fractiles (0.9, 0.5, and 0.1) indicate the range of individual susceptibility, from the 90th percentile (least susceptible), 50th percentile (average susceptibility) to the 10th percentile (most susceptible).

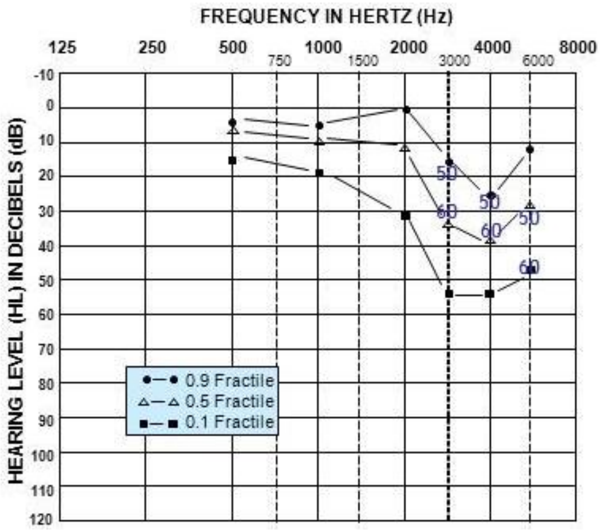


**Figure 3:** NIPTS predicted by ANSI S3.44 (1996) from use of a digital PLD for 4 hours per day, 5 days per week for 10 years at 90 % of the maximum volume control. The symbols “50” and “60” denote average hearing threshold levels for a 50-year-old and 60-year-old man according to ANSI S3.44 (1996), Annex B. Population fractiles (0.9, 0.5, and 0.1) indicate the range of individual susceptibility, from the 90th percentile (least susceptible), 50th percentile (average susceptibility) to the 10th percentile (most susceptible).

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# Novel personal noise dosimeters

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## INTRODUCTION

Personal noise dosimeters have been used for decades as noise exposure measurement devices, constituting an important part of a program to protect workers for over exposure; however, they remain expensive and are not used as widely as would be beneficial. Our goal was to develop a new dosimeter that would be less expensive, easier to operate, and which would meet all EU regulatory requirements.The purpose of this paper is to evaluate and report on the current progress of this project.

## METHODS

### Frequency response test physical setup

Acoustic measurements were made in an anechoic chamber at either University College London's Ear Institute or London South Bank University. A calibrated Bruel and Kjaer (B&K) 4192 reference microphone (+/- 0.5 dB from 20 Hz to 20 kHz) was positioned 1 meter on axis from a single Samson Resolve A8 powered speaker (frequency range from 50 Hz - 20 kHz). The B&K reference microphone was angled 90 degrees to the incident plane wave and the soundBadge prototype's microphone was positioned 1 cm opposite the reference microphone (both were positioned at 90 degrees to the direction of travel of the acoustic plane wave in accordance with the manufacturer's suggested positioning).

### Frequency response test stimuli and analysis

Custom Labview software was used to generate the sound stimulus and simultaneously capture responses from both the reference microphone and the soundBadge. Ten second bursts of frozen periodic random noise were used as the stimuli to avoid spectral splatter. The stimuli were generated by National Instruments (NI) 9263 16-bit ADC at 51,200 Hz and sent to the powered speaker at level of approximately 80 dB SPL, 100 bursts were presentations were made.

Responses from the reference microphone and the soundBadge taken after its analog microphone compensation filter or after its A and C-weighted filters were synchronously sampled by an NI-9234 24-bit DAC at a rate of 51,200 Hz and averaged. The frequency response of the soundBadge was assessed by taking the ratio of the Fourier transforms of the soundBadge to that of the reference microphone (Figure 1).

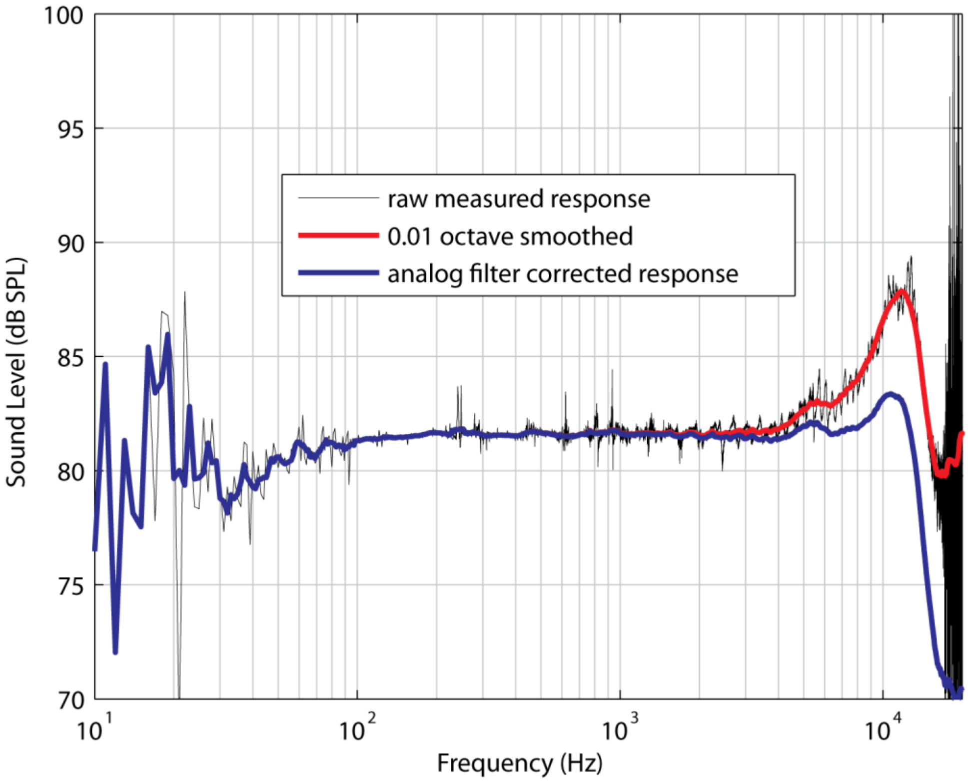


**Figure 1:** soundBadge raw microphone response (black), the smoothed response (red), and the response after processing by the device's analog correction filter (blue) shows the raw measured output reletive to the reference mic. This graph shows a relatively flat frequency response is achieved through an analog filter correction for the 12 kHz peak.

## Simulation of industrial environment test physical setup

The overall performance of the prototype soundBadge was compared to 3 calibrated industry standard reference devices (a Rion NC-74 class I calibrator @ 1 kHz 94 dB SPL was used for sound level meter calibrations before each measurement). Two sound level meters (Norsonic NOR 140 Class 1 meter, and Norsonic NOR 132 Class 2 meter) and a Cirrus CR110A dosebadge were used for the comparison. A-weighted levels and noise dose measurements were made. All tests took place at London South Bank University either in the anechoic chamber, the acoustic and lighting laboratory, or the reverberation chamber. These locations comply with $L_{Aeq}$ measurement requirements according to EU standards. Sound level meters were placed on a tripod at listening position of a worker. Dosimeters were worn (CR110A) or held (soundBadge) also at the listening position.

## Simulation of industrial environment stimuli and analysis

Three noise types simulating a normal factory work environment were used: drilling, wood sanding and hammering metals. Measurements were timed to 2 minutes (120 s) apart from the Cirrus CR110A which has no display and whose recorded data was read at the end of all the sessions. A-levels were measured and dosages were calculated from these average equivalent A-weighted levels. Calculations were made according to the standard EU formulas (IEC 61252) after the assumption that these stimulated work noises would constitute 1 hour of an 8 hour work day.

## RESULTS

### Frequency response

Measured frequency response between 31.5 Hz to 8 kHz for A and C-weighting were within +/- 1.27 dB and +/- 0.9773 dB from the targets specified in EU regulations (IEC61252:2002-03 ; IEC61672-1:2002-05). The average deviation from the targets 31.5 Hz and 8 kHz were 0.3488 +/- 0.2855 and 0.3598 +/- 0.3271 for A and C weightings respectively. These were within class I weighting tolerances when measured at high levels (measurement was made at 81.5 dB SPL @ 1 kHz). Low frequency range limitations of the sound source prevented measuring below 30 Hz (see noise indicator bands on Figure 2). High frequency responses, between 8 kHz and 12.5 kHz, were within +/- 2.16 dB and +/- 2.22 dB of the target (Figure 2) and were also within class I specifications at (or presumably above) 80 dB SPL. Note that 80 dB SPL is the required lowest level a sound exposure meter must accurately measure according to EU specifications (IEC61252:2002-03).

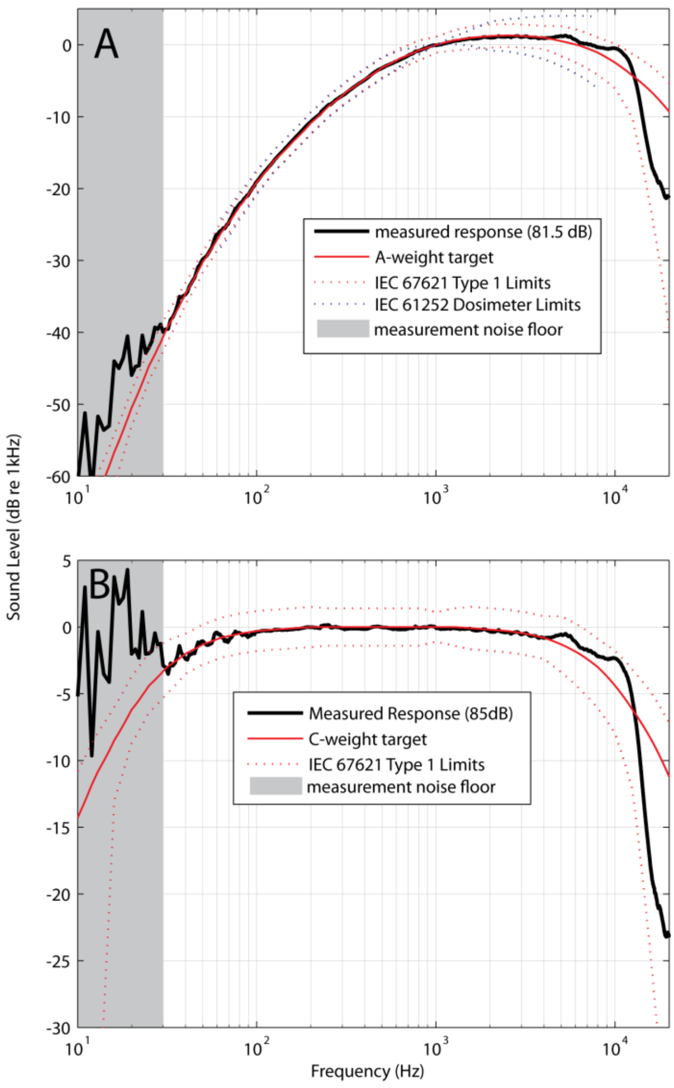


**Figure 2:** soundBadge frequency reponse measured after its analog A or C-weight analog filter (Panel A and Panel B respectively) compared to allowed EU regulatory limits shows the device performs within the required frequency weighting specification for noise dosimeters (as specified by IEC 61252 from 63 Hz to 8 kHz required) and is within Class I sound level meter tolerance from 30 Hz when measured at 81.5 dB SPL.

## Simulation of industrial environments

Over the 3 locations and several simulated work environments the two calibrated sound level meters were within +/- 2 dB of each other when reporting equivalent A-weighted levels (NOR132 relative to NOR140 was within 0.9 dB to -2.0 dB, mean = 0.9167, std = 0.6274). The soundBadge prototype had A-weighted levels within +/- 2.9 dB of both sound level meters (relative to NOR140, min = -2.7 dB, max = 2.6 dB, mean = 1.2 dB, std = 1.15 dB; and relative to the NOR132, min = -2.9 dB, max = 2.0 dB, mean = 1.7 dB, std = 0.9 dB) (Table 1).

**Table 1:** Comparison of two sound level meters (a class I NOR140 and a class II NOR132) with the soundBadge prototype sound exposure meter for several simulated work environments (top of table). Representative measurements of the activities were made over 2 min durations and it was assumed that the work day would consist of 1 hour of this activity. In order to compare with CR110A the overall measurements were combined. All devices produced similar overall dose measurements and soundBadge was within 3 dB of the sound level meters for all measurements.

| Environment | SOURCE | SLM Type | DURATION (sec) | SPL (dBA) | LAmax (dBA) | LEP,8h (dBA) | Noise Dose % |
|---|---|---|---|---|---|---|---|
| Office | Metal Filing | Nor 140 | 120 | 97.0 | 101.9 | 88.0 | 198.6 |
| | | Nor 132 | | 99.0 | 102.7 | 90.0 | 315.2 |
| | | soundBadge | | 97.7 | 102.3 | 88.7 | 233.4 |
| | Plastic Cutter | Nor 140 | | 97.6 | 101.0 | 88.6 | 228.1 |
| | | Nor 132 | | 98.8 | 101.2 | 89.8 | 301.0 |
| | | soundBadge | | 96.3 | 102.1 | 87.3 | 168.9 |
| Reverb Chamber | Drilling Plastic | Nor 140 | | 84.8 | 95.7 | 75.8 | 11.9 |
| | | Nor 132 | | 83.9 | 95.4 | 74.9 | 9.6 |
| | | soundBadge | | 84.6 | 100.7 | 75.6 | 11.3 |
| | Sanding Wood | Nor 140 | | 89.8 | 92.9 | 80.8 | 37.6 |
| | | Nor 132 | | 90.0 | 93.4 | 81.0 | 39.4 |
| | | soundBadge | | 87.1 | 95.1 | 78.1 | 20.2 |
| | Hammering Metal | Nor 140 | | 88.4 | 93.2 | 79.4 | 27.2 |
| | | Nor 132 | | 89.0 | 94.9 | 80.0 | 31.3 |
| | | soundBadge | | 91.0 | 102.0 | 82.0 | 49.6 |
| Anechoic Chamber | Hamemring Metal | Nor 140 | | 89.5 | 99.6 | 80.5 | 35.1 |
| | | Nor 132 | | 90.1 | 97.0 | 81.1 | 40.3 |
| | | soundBadge | | 89.4 | 97.6 | 80.4 | 34.3 |
| All | Through All | Nor 140 | 720 | 92.4 | 101.9 | 76.4 | 13.8 |
| | | Nor 132 | | 93.5 | 102.7 | 77.5 | 17.6 |
| | | soundBadge | | 92.3 | 102.3 | 76.3 | 13.3 |
| | | CR110A | 1758 | 87.8 | 121.1 | 75.7 | 11.5 |

Overall noise dose from the measured devices spanned a range of 11.5 % to 17.6 % (CR110A and NOR132). The soundBadge and the NOR140 were 13.8 and 13.3 % respectively. The CR110A required a separate reader and consequently the total time over which it was operated was used to calculate its dose, therefore the 11.5 % dose may have registered low due to the fact that this device was averaging sounds over a longer time. However, since the duration of time the CR110A spent in the loud sound environment was significant (720 seconds of the total 1,758 s spent averaging) those loud sounds dominated the average.

## CONCLUSIONS

For sound level measurements above 80 dB SPL, the prototype soundBadge has a measured frequency weighting within EU sound level meter class I tolerance specifications for sounds between 30 Hz and 12.5 kHz. In simulated tests soundBadge produced accurate noise dose measurements comparable to CR110A and dosages calculated from both class 1 and class 2 sound level meters. It produced the closest agreement with the NOR140 class I reference meter for overall dosage.

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# Modeling the incidence and prevalence of noise-induced hearing loss in New Zealand

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## INTRODUCTION

Noise-induced hearing loss (NIHL) is recognised as a significant health and disability issue both in New Zealand (NZ) and worldwide. Noise exposure can lead to damage in the inner ear and loss of hearing ability, particularly to high frequency sounds; poor speech detection and discrimination; an inability to hear in background noise; and tinnitus. The impact on the individual varies but it can reduce employment options and cause social withdrawal, isolation and depression.

The World Health Organisation estimates that over 250 million people have significant hearing loss and that approximately 16 % of these cases result from excessive noise (Smith 2004). There is also a high economic cost; for example in Australia hearing impairment is estimated to cost $11.6b (1.6 % of GDP) annually and NIHL is thought to account for about 30 % of this cost (Access Economics Pty Ltd 2006). The Accident Compensation Corporation (ACC) in NZ reports a steady increase in the number of NIHL claims over recent years at an increasing cost for rehabilitation (Thorne et al. 2008).

Epidemiological data on NIHL has been collected using various methods including quantitative hearing assessment, self-reports (e.g. European Agency for Safety and Health at Work 2005), questionnaires (e.g. Palmer et al. 2000, 2001) and the number of people receiving compensation for NIHL (Thorne et al. 2008). Estimates of the incidence and prevalence of NIHL in different countries vary considerably. This variation is likely due to differences between the populations and their noise exposure, and includes: variations in the audiometric criteria for defining degree of hearing loss; differences in hearing conservation programs and use of personal hearing protection; and in criteria for attributing the proportion of hearing loss due to noise exposure rather than age or other disease. Based on the WHO definition for substantial or significant hearing loss (> ave 41 dB loss for 0.5, 1, 2 and 4 kHz), an estimated one sixth (16 %) of the population with hearing loss worldwide is attributable to occupational noise exposure (WHO 2002). This figure is corroborated by a USA assessment of the contribution of occupational noise exposure to total deafness rates, giving a range from 7 % in developed nations to 21 % in developing regions (Nelson et al. 2005). In the USA it is estimated that between 9 and 11 million people have NIHL and 30-40 million are at risk because they work in noisy environments (Crandell et al. 2004; NIDCD 2005). Hearing loss and tinnitus accounts for 10 % of the disabilities in the US armed services; the third highest disability (Humes et al. 2006).

In New Zealand it is difficult to identify exactly how many people are affected by NIHL and how many are at risk as there are very limited published data in this country. In 1984 the Department of Health estimated that about 50 % of adult hearing loss in NZ was due to noise (Hearing Report 1984). From 1992 to 1998, there were 2,411 validated cases of NIHL reported to the Notifiable Occupational Diseases System

(NODS), a voluntary national register (Driscoll et al. 2004). From 1998 to 2000 there were a further 709 notifications (Statistics New Zealand 2000). While these voluntary reports are not a reliable indication of the prevalence of NIHL, they place it as the second most *voluntarily* reported occupational disease in the country (after occupational overuse syndrome). McBride (2005) estimated that 25 % of the NZ workforce are affected by noise at work. In our review of the claims for NIHL up to 2006 we showed that the new claims rate for NIHL had been steadily increasing over the previous ten years, with a noticeable increase between 1995-99 and 2000-2004 (Thorne et al. 2008).

It is difficult to estimate the effects of occupational risks on the overall health of communities. Although there is growing acceptance of the importance of objective measurements, the health effects of many occupational risk factors have not been quantified. Recognising the need to quantify the disease burden related to occupational noise, and to understand the distribution of the burden within populations, the World Health Organisation has published a report outlining a method for "occupational health professionals to carry out more detailed estimates of the disease burden associated with hearing loss from occupational noise both at national and subnational levels" (Concha Barrientos et al. 2004). Together with an introductory volume on assessing environmental burden of disease (Prüss-Üstün 2003) these provide guidelines for the assessment of the burden of disease associated with NIHL and form the basis of this study. Essentially the approach involves: 1. Estimating the number of workers in each occupation and sector. 2. Estimating the proportion of workers by occupation and sector exposed to potentially harmful noise. 3. Estimating the relative risk of developing noise induced hearing loss with noise exposure. 4. Calculating the expected prevalence of hearing loss in each occupation and sector by multiplying the exposure rate by the number of workers and computing the proportion with noise induced hearing loss based on the relative risk compared to non-exposed workers.

In this study we have adapted the WHO model and used it as a method to estimate occupational NIHL in NZ and then attempted to verify these estimates by sample field measurements of noise levels in selected New Zealand industries. Here we provide preliminary estimates and results.

## METHODS

The first part of the approach was to make estimates based on published international data. This used estimates of the proportion of the population in each sector and occupational setting exposed to noise levels greater than 85 dBA, determined from tables published by Concha-Barrientos et al. (2004). We then used the NZ Census data (Statistics New Zealand 2006) to estimate the number of people at risk by occupation, age, gender and ethnicity in this country, combined with risk of developing NIHL estimated by ISO (1999) and Prince et al. (1997) to obtain estimates of prevalence which were then converted to incidence using the DISMOD II software. Following this we verified our estimates and began to determine sensitivities to our projections through field studies of noise levels in different sectors.

### Exposure estimation and relative risks of noise exposure

Initial estimations of noise exposure were undertaken using an occupational category approach based on international noise exposure data (NIOSH 1998) and were subsequently refined and verified using NZ data from field studies. This provided estimates of the proportion of workers in each workplace type (disaggregated as much as possible) exposed to low (<85 dBA), moderately high (85-90 dBA) or high (>90 dBA) noise levels. Occupation specific exposure estimates were then merged with the NZ Census workforce data to determine the proportion of the New Zealand population at risk to exposure at low, medium and high noise levels in 2006. Other estimates were made for previous Census years but these are not described here. For the purposes of this study, estimates were derived for relative risks of hearing loss at >25 dBHL

## Field measurements

Measurements were made of noise levels using static sound level measurements and dosimetry in selected sectors and companies to verify and revise the estimates of noise exposure. Ninety-nine companies were visited across different economic subsectors and dosimetry measurements were made on 529 workers (Table 1). This number includes personal noise exposure levels in agriculture, obtained from Dr David McBride (82 production workers) and data on personal noise exposure levels in the mining sector obtained from a drilling rig (4 production workers).

Noise levels from a selection of machinery and workplace environments were assessed using a calibrated sound level meter (Solo SLM, 01 dB-Metravib). Sound measurements were taken at a distance 1 m from the source of the noise. For each machine, the duration of measurement was chosen to obtain a recording that was representative of the typical noise produced by the selected machine, while being used to perform a typical job or process. Personal noise exposure over an entire work shift was assessed using a calibrated dosimeter (CEL-350 dBadge, Casella) attached to the shoulder of each employee. The dosimeter was set to display ISO parameters, including $L_{Aeq}$ and $L_{peak}$. The employee wore the dosimeter, without removing the device, for the whole of the shift for that day.

**Table 1:** Profile of companies visited and employees tested

| **Economic Subsector** | **Companies visited** | **Employees tested** | |
|---|---|---|---|
| | | Production | Non-production |
| Agriculture | 6 | 99* | 2 |
| Mining | 1*** | 4** | 0 |
| Construction | 3 | 15 | 4 |
| Manufacturing | 37 | 188 | 18 |
| Transportation, Electric, Gas, Sanitary Services | 9 | 43 | 9 |
| Trade | 14 | 50 | 5 |
| Finance and Public Administration | 7 | 8 | 35 |
| Services | 23 | 86 | 20 |
| **TOTAL** | **99** | **493** | **93** |

* Including additional data for 82 production workers, for whom only dosimetry data are available
** Including additional data for 4 production workers, for whom only dosimetry data are available
*** Data from a drilling rig

RESULTS

**Noise measurements**

The mean $L_{Aeq}$ for production workers was largest for those in the agriculture sector (86.3 dB), followed by mining, construction, manufacturing, transport/utilities, retail, services, finance and public administration (Figure 1). The mean $L_{Aeq}$ levels measured for non-production workers were lower than production workers in each sector, but were similar between sectors ($L_{Aeq}$ values ranged from 68.6 dB for retail to 73.8 dB for construction). This may be expected since the non-production workers tended to be in offices, away from sources of noise (although occasionally non-production workers, particularly in retail, received high LCpeak levels).

The largest range of $L_{Aeq}$ for non-production workers, was found in the manufacturing sector and the service sector. In manufacturing this may be due to the variation in the size of the facilities as both large and very small enterprises were visited. For the smaller facilities, non-production, office-based employees were often working in the vicinity of machinery, maybe in an adjacent room. In addition, office based staff in smaller facilities may be more likely to enter noisy areas during the working day. However, the distribution of $L_{Aeq}$ values across small and large companies was not found to be substantially different. For the services sector, the range of individual noise exposure may be explained by the variety of subsectors in this sector, covering for example panelbeating to libraries.

Among the different sectors mining, construction, agriculture and manufacturing had the greatest percentage of employees exposed to noise levels above 85 dB $L_{Aeq}$ (75.0 %, 66.7 %, 57.9 % and 42.6 % respectively; Figure 2). For all other sectors, less than 25 % of employees were exposed to noise levels exceeding 85 dB $L_{Aeq}$, with 0 % in finance and public administration.

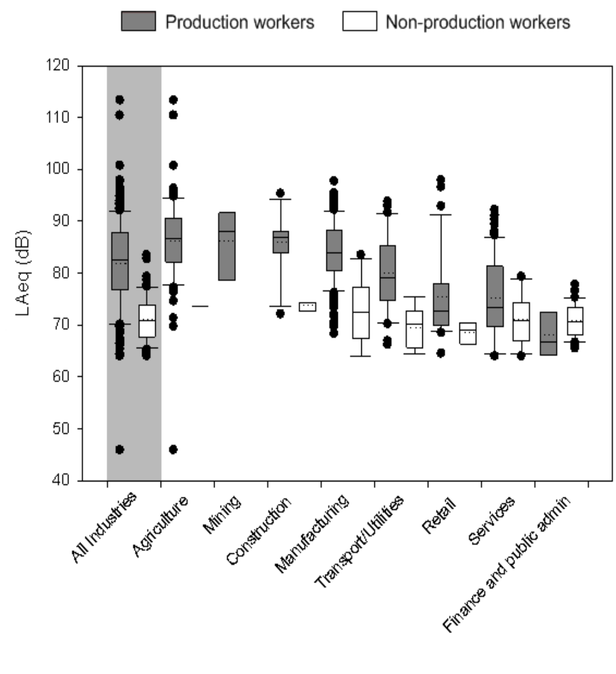


**Figure 1:** The range of $L_{Aeq}$ measured for all production and non-production workers who were monitored in each sector, shown as boxplots of employee $L_{Aeq}$ by sector. The solid line within the box marks the median $L_{Aeq}$. The dashed line is the mean $L_{Aeq}$. The box boundaries show the 25th percentile and 75th percentile. Error bars indicate the 90th and 10th percentiles.

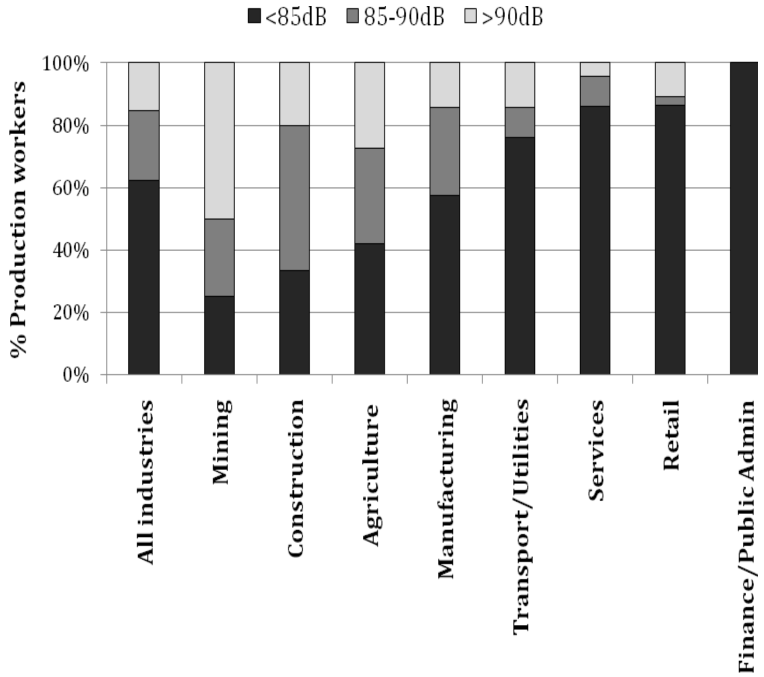


**Figure 2:** Percentage of production workers relative to exposure criteria at 85 and 90 dB $L_{Aeq}$

## Model estimates

Based on the noise measurements undertaken in different industries, the proportion of workers exposed to levels of noise greater than 85 dBA in each sector was similar to that estimated by Concha-Barrientos et al. (2004) for all sectors except Agriculture, Manufacturing and Construction, Transportation and Services where our NZ proportions were substantially higher (Table 2). Using both the WHO data and our field measurements we have estimated the prevalence and incidence of NIHL within the workforce and population, in 2006 (Table 3). Our estimates of the prevalence (rate per 100,000) of NIHL (≥25 $dBHL_{Ave1,2,3,4kHz}$) in the *workforce,* in 2006, range from 1,473 (based on the WHO calculations) to 2,140 (based on New Zealand data collected in this study). This gives an incidence in the workforce ranging from 54 to 77 new cases of NIHL per 100,000 workers. Our estimates of the prevalence of NIHL (≥25 $dBHL_{Ave1,2,3,4kHz}$) in terms of total numbers of the *New Zealand adult population*, in 2006, range from 51,962 (based on the WHO calculations) to 72,716 (based on New Zealand data collected in this study).

The model estimates that the prevalence rates of NIHL (cases/100,000) for males and females is greatest among the industries with exposures greater than 90 dBALeq in the order of Mining, Construction, Manufacturing and Agriculture. Taking into account the different participation rates in these sectors the *total number* of NIHL cases is greatest in Manufacturing and Construction, followed by Agriculture and Trade.

**Table 2:** Proportion of workers exposed to noise levels ≥ 85 dBA according to the WHO estimates and to those developed by our measurements

| | **Production Workers** | |
|---|---|---|
| **Economic sector** | WHO Estimate | NZ Estimate |
| Agriculture | 0.20 | 0.57 |
| Mining | 0.85 | 0.75 |
| Manufacturing | 0.22 | 0.39 |
| Electricity | 0.15 | 0.20 |
| Construction | 0.18 | 0.53 |
| Trade | 0.13 | 0.12 |
| Transportation | 0.12 | 0.22 |
| Finance | 0.02 | 0.00 |
| Services | 0.03 | 0.11 |

**Table 3:** Estimated exposure rates (/100,000) and numbers with NIHL in the NZ workforce (N=1,985,781) and total adult population (N=4,027,938) based on 2006 census data

| | **Workforce** | | **Population** | |
|---|---|---|---|---|
| **Measure** | **WHO** | **NZ** | **WHO** | **NZ** |
| Current Exposure Rate | 7,821 | 10,333 | - | - |
| NIHL Prevalence Rate | 1,473 | 2,140 | 1,290 | 1,805 |
| NIHL Incidence Rate | 54 | 77 | 27 | 38 |
| Number Currently Exposed | 15,5315 | 205,193 | - | - |
| NIHL Prevalence | 29,242 | 42,497 | 51,962 | 72,716 |
| NIHL Incidence | 1,077 | 1,537 | 1,077 | 1,537 |

## CONCLUSIONS

Noise-induced hearing loss (NIHL) is a significant occupational health problem that has considerable individual and societal costs. Understanding the demographics and industry distribution of NIHL is important to defining targeted intervention strategies to prevent the hearing impairment. As there is little understanding of the epidemiology of NIHL in New Zealand this study modeled the incidence and prevalence of NIHL in the NZ working population utilizing a modified version of the WHO Burden of Disease model for occupational hearing loss (Concha-Barrientos et al. 2004). With knowledge of population demographics and distribution of the working population across industry, and with some assumptions about the risk of developing hearing loss with exposure, the model has allowed us to estimate the incidence and prevalence of NIHL across age and industry. Based on pre-existing data (NIOSH) the model generated a prevalence figure of 1,473 per 100,000 in the workforce, which represents about 19 % of the hearing impaired in the workforce, a number which represents our lower limit. Recalculation using observed data suggests a prevalence of 48994 (29 % of workforce hearing loss). Based on these population data it is estimated that in 2006 between 1.35 and 1.75 % of the New Zealand population had a hearing loss with a significant contribution from noise exposure. Given the estimated prevalence of hearing loss in the New Zealand population is 10 % (Greville 2005) then NIHL affects between 13.5 % and 17.5 % of the hearing impaired population.

Refinement of model-based estimates of the range of feasible workforce exposure rates will be made through ongoing research. The model developed provides a matrix into which data from this research can be incorporated.

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# Exposure to very high noise levels and the effect of double hearing protection

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## ABSTRACT

The risk of noise induced hearing loss increases for operators working in extreme noise environments. Although the use of earplugs and earmuffs as 'double protection' may be the obvious solution, the attenuation of a double hearing protection system is not simply the addition of the individual component attenuations. The choice of devices and the implementation can also result in a number of outcomes: the integration of communications wiring may cause acoustic leaks, the wearer may be over-protected and feel isolated and the interaction of earplug and earmuff may cause discomfort and discourage take-up. A variety of hearing protection devices currently on the market have been examined with a view to their use in a double protection system. Wireless technologies enable the provision of a communications signal to an earplug worn beneath an earmuff without compromising the attenuation benefit of the double protection system. Adaptive systems, such as the 'tactical' communications earplugs and techniques such as adaptive digital active noise reduction, provide a method of tailoring levels of hearing protection to the noise environment. Using military operators as an example user group the application of a range of earplug devices as part of a double protection system have been considered and illustrations have been provided of their relative abilities to meet the users' protection requirements.

## INTRODUCTION

The noise encountered by many military personnel can be extremely high due to the nature of the vehicles and equipment they operate and the presence of additional noise sources such as communications and audio warning systems. The noise to which aircrew are exposed can reach levels of around 120 dBA and with the introduction of the next generation of Combat Aircraft the exposure of ground and deck crew is predicted to reach 150 dBA (Bjorn 2008). Similarly for land base operators: the crew of heavy tanks and armoured fighting vehicles may well be exposed to levels between 110 dBA and 120 dBA and the weapons fired by the infantry can produce peak pressure levels of some 190 dB (Paakkonen & Lehtomaki 2005; Buck & Hamery 2010).

In these environments, the noise attenuation provided by earmuffs or earplugs when worn singly can be inadequate to bring the daily personal noise dose down to below the legislative limits. The simplest solution would appear to be to recommend the wearing of earplugs underneath an earmuff. However, this does not provide the levels of attenuation that might be expected if the attenuation values for each device when worn singly are simply added together. There are other issues that also need to be taken into account when wearing double hearing protection systems, such as the provision of communications and the ability to hear external warnings.

DOUBLE HEARING PROTECTION

**Attenuation and bone conducted noise**

The most common hearing protection devices aim to reduce the level of sound transmitted along the auditory canal to the inner ear. However, noise can reach the cochlea by three other routes collectively known as bone conducted noise (Tonndorf 1972). Noise that impinges upon the body may be transmitted by the flesh and bone of the head, causing the cartilage of the ear canal to vibrate and to generate additional sound pressure levels in the ear canal in front of the ear drum. This is known as the 'occlusion effect', which dominates at frequencies below 2 kHz (Khanna et al. 1976; Stenfelt et al. 2003). Noise may also be transmitted to the cochlea directly by the bones of the skull and by the fluid contained within the inner ear (including the semi-circular canals). These last two transmission routes are difficult to separate and dominate at frequencies above 2 kHz. When the auditory canal pathway is attenuated sufficiently, these bone conduction pathways to the cochlea become increasingly important.

The highest levels of attenuation achieved by a double hearing protection system that have been reported were obtained by Berger (1983). He inserted E.A.R.® 'Classic'™ foam earplugs as deeply into the ear canal as possible (100 % insertion depth) and then placed earmuffs over the ears. Decreasing the volume of the earshells or increasing the mass of the earmuffs did not affect the level of attenuation achieved in this double protection system. This, together with measurements using different earplug insertion depths, appeared to show that the earplug forms the driver in the level of attenuation possible in a double protection system.

In a previous experiment, the authors investigated the role of the earmuff in double hearing protection. A miniature microphone was clipped inside an Active Noise Reduction (ANR) earmuff which was worn over a custom moulded earplug that incorporated a microphone at the tip. The Sound Pressure level (SPL) could therefore be measured simultaneously beneath the earmuff and in the wearer's ear canal (Tubb et al. 2005). The results showed that the SPL in the ear canal was unchanged whether the earmuff was left in its passive mode or whether the ANR was activated. The SPL measured under the earmuff showed that the ANR system operated correctly, but the additional attenuation provided by the ANR system was apparently 'lost' when measured in the earcanal, on the occluded side of the earplug.

The reason for the apparent loss in attenuation of the earmuff when worn in a double protection system has yet to be established and is likely to be due to a complex interaction of the earmuff with both the earplug and the wearer's head. At frequencies above 2 kHz, the auditory canal is sufficiently attenuated that higher levels of attenuation can only be achieved by shielding the head and torso. At frequencies below 2 kHz, the occlusion effect must be overcome. Although the occlusion effect can be overcome by inserting foam earplugs sufficiently deep to prevent movement of the cartilaginous walls of the ear canal, the same level of protection is unlikely to be achieved in the field with real users due to the difficulty of fitting these types of earplug sufficiently deep. There may also be effects due to the interaction of the earmuff and earplug either directly, due to contact between the surfaces of the two devices, or indirectly, due to the connection of the two devices by the air under the earmuff or by flanking pathways including the tissues of the head and ear.

### Communications

The noise from the environment is not the only source of noise reaching the ear of military operators; they may also receive a communications (comms) signal via the loudspeaker in the earmuff. The wearing of a passive earplug beneath the earmuff will result in the attenuation of the comms signal along with the environmental noise. The wearing of a comms earplug underneath the earmuff enables a reduction in the environmental noise whilst retaining a clear comms signal. This has an additional benefit in that this reduction in the noise allows the comms signal itself to be reduced to maintain the same signal to noise ratio, thereby reducing the total noise at the ear.

Most comms earplugs currently available rely on a cable to provide the signal to the loudspeaker enclosed within the body of the earplug. This cable must be located carefully to minimise the level of acoustic leak that occurs if the earseal is broken.

### Isolation

It is important when choosing any hearing protection system that it meets the requirements of the end user and that the hearing protection with the highest levels of attenuation is not chosen simply in order to meet the legislative limits. In the guidance to the Control of Noise at Work Regulations (CNAWR):2005 (HSE 2005), a level of 70 dBA is set as the lower limit on noise at the ear, to help prevent overprotection and the associated feelings of isolation. Excessively high levels of hearing protection (over and above that required to meet the noise exposure limits) reduce the reliable detection of important audio cues taken from the working environment and may constitute a safety risk or limit operational effectiveness.

## HEARING PROTECTION DEVICES

A review of commercially available hearing protection devices and some near future technologies was made to establish the best performing devices and those with the best attributes for use in a double hearing protection system, bearing in mind the issues mentioned in the previous section.

### Earmuffs and earplugs

There are three main types of earmuff currently on the market: passive, electronically enhanced and pass-through. Electronically enhanced earmuffs can include communications earmuffs and earmuffs incorporating ANR systems. Pass-through systems include ‘shooters’ earmuffs and tactical earmuffs designed to transmit sound from the environment through the earmuff to the ear.

Earplugs are also available in passive, electronically enhanced and fitted with filters. Over the last ten years or so, custom moulded earplugs have become more widely available. A comparison of personally moulded earplugs including one ‘self-moulded’ earplug by the UK’s Health and Safety Laboratories found that the attenuation performance of the earplugs can be significantly lower than the supplied manufacturer’s data (Shanks & Patel 2009).

Earplugs with acoustic filters are available that aim to provide a more selectable level of hearing protection compared to a solid passive earplug**.** These include ‘musicians’ earplugs in which the filter aims to produce attenuation with a flat frequency response, although filters with other spectral characteristics are also available. A number of earplugs are now available that incorporate ANR and tactical earplugs that have primarily been developed for the military are becoming more prevalent.

## ASSESSMENT OF EARPLUGS AND DOUBLE HEARING PROTECTION

The wide range and variety of hearing protection devices on the market were examined for their usefulness in extreme high noise environments and three candidate earplug technologies were down-selected for test as part of a double protection system. The main factors considered in the selection process were: the levels of noise attenuation; provision of a communications signal and over-protection.

A communications earplug offers the best approach to attenuating the ambient noise whilst retaining high speech intelligibility. Whilst the wireless technologies described in the previous section are novel, they are not currently commercially available and so wired comms earplugs were used in the assessment. Three communications earplugs were down-selected for test: the Mini-CEP from Communications & Ear Protection Inc., the ‘Omara’ earplug from Amplifon and a tactical earplug example.

- The Mini-CEP can be either personally moulded or provided with a foam tip for generic fit. The device consists of a transducer housing and a foam/moulded canal tip that provides passive attenuation. The canal tip has a central hollow ‘core’ that allows the comms signal to pass into the ear canal without being attenuated.
- The Omara earplug is a silicone custom-moulded device. It can be fitted with one of a range of interchangeable filters that use the physics of small cavities to alter the attenuation of the earplug. The earplug provides a comms signal direct into the earcanal.
- A tactical earplug that can be either personally moulded or fitted with a foam tip for generic fit. The device allows the electronic pass through of ambient sound and direct speech to the ear in low noise environments. It provides comms directly into the earcanal and uses an in-ear microphone for the transmission of speech. The device also provides protection against high level impulse noise.

In order to understand the comparative performance of these particular devices and the benefits they may provide for military operators, measurements of their attenuation performance were made using the Real Ear Attenuation at Threshold (REAT) technique (ANSI S12.6, 1997). The attenuation provided by the Mini-CEP and the Omara earplugs was measured when used in combination with a UK flight helmet.

However, as the tactical earplugs are designed to amplify low levels of sound, the attenuation of the selected device could not be measured using the standard REAT technique and, instead, it’s attenuation as a function of the pass-through functionality was measured using a Brüel & Kjær (B&K) Head and Torso Simulator (HATS).

The assessment of these devices formed part of a larger research program and only a small number of subjects were used at this stage to provide an indication of comparative performance. Full measurements should be undertaken using a recognized test-house to the relevant standard if the solutions are to be taken forward.

RESULTS

**Attenuation of Mini-CEP and helmet**

The mean attenuation and associated standard deviations measured for the helmet and the Mini-CEP used in combination are shown in Figure 1. Measurements were made for 8 subjects at the frequencies specified in the REAT standard. High levels of attenuation were exhibited right across the frequency range and, hence, due consideration must be given in any application of this double protection system to ensure it does not constitute over-protection.

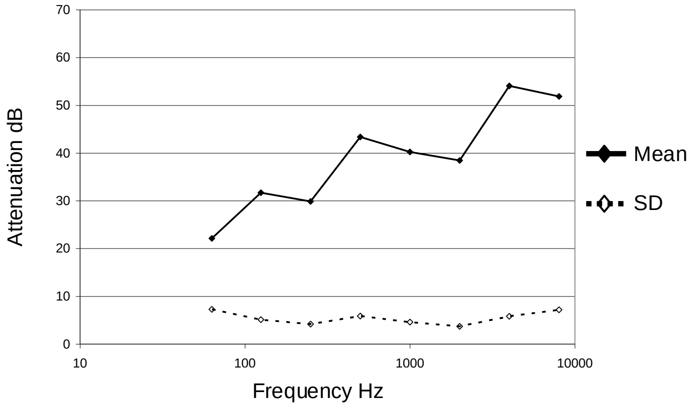


**Figure 1:** Mean attenuation and associated standard deviations of helmet plus Mini-CEP used as a double hearing protection system (8 subjects)

**Attenuation of Omara earplug and helmet**

The mean attenuation and associated standard deviations for the Omara earplug fitted with a range of filters providing different levels of attenuation (the LD10, LD14, LD18, LD22 and LD24 filters) are shown in Figure 2 (a). Measurements were made on 4 subjects using the REAT technique over an extended range of 24 frequency bands. The effect of the different filters can be seen by the spread in the levels of attenuation at frequencies below 630 Hz.

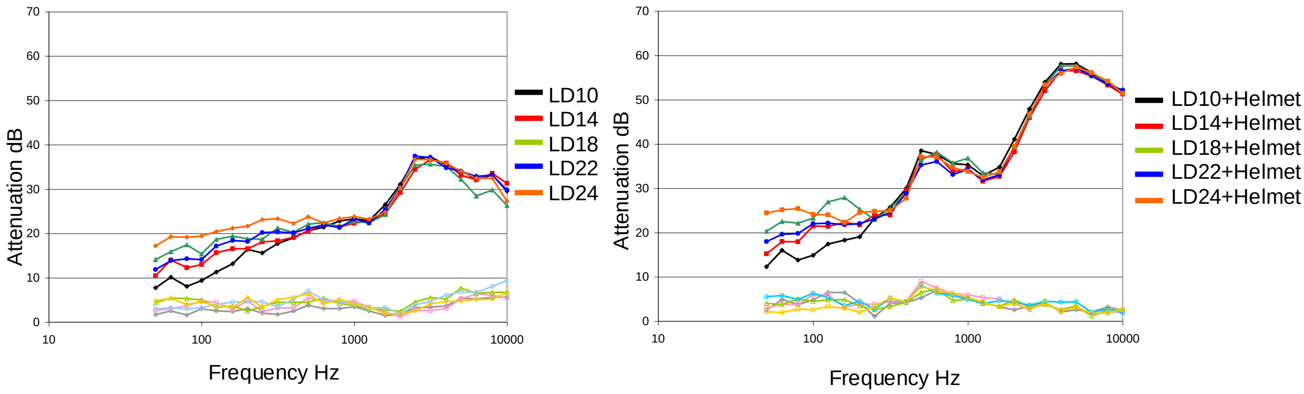


**Figure 2:** Mean attenuation and associated standard deviations of the helmet plus Omara earplug with different filters used as a double hearing protection system (4 subjects)

When the helmet was worn over the Omara earplug, the attenuation showed a much reduced range of variation due to the different filters, as shown in Figure 2 (b). The variation in attenuation afforded by this double protection system occurred at frequencies below 250 Hz. The reduction in the range of frequencies over which variation in attenuation was exhibited is probably due to complex interactions between the helmet, earplug and the wearer's head. Whilst it is not currently clear what the exact mechanisms are, the limited range of variability must be taken into account in any application of this double protection system to ensure it provides an effective solution.

### Attenuation of the Tactical Earplug

The operation of the tactical earplug was measured when fitted to the B&K HATS in Pink noise generated at five different Overall Sound Pressure Levels (OASPLs). The dynamic pass-through system of the earplug was set to off, to provide the passive performance of the earplug, and to its minimum, mid and maximum settings. For each condition the SPL was measured at the microphones within the ears of the HATS. The results are shown in Figure 3.

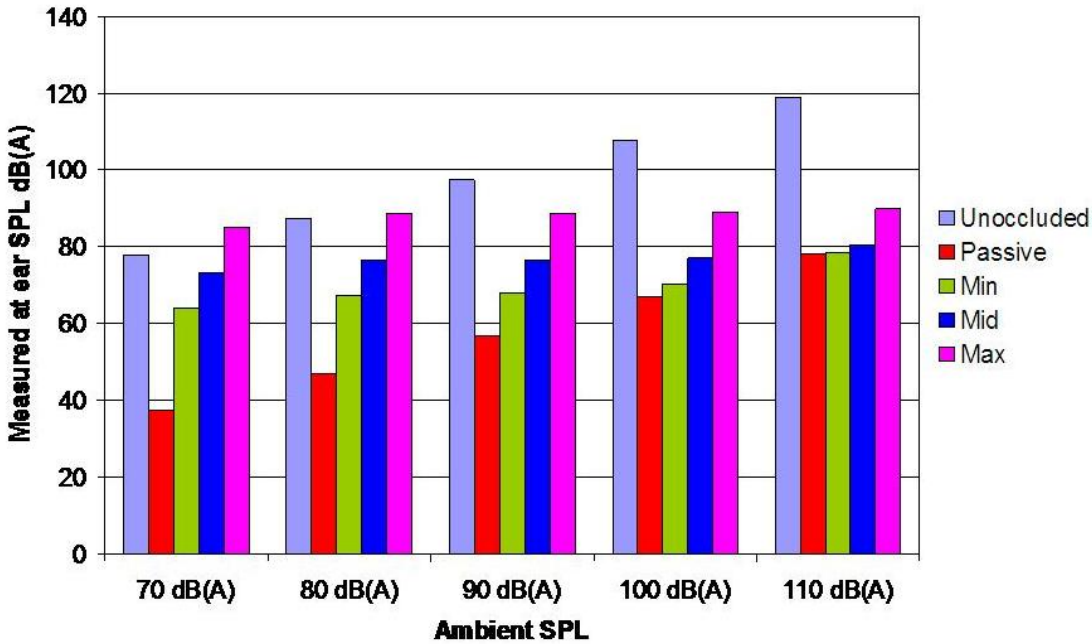


**Figure 3:** Overall A-weighted SPL measured on the B&K HATS for the tactical earplug with different settings of the dynamic pass-through system in increasing levels of Pink noise

The figure shows that as the ambient noise field (unoccluded) was increased in level, the OASPL on the occluded side of the earplug when the dynamic pass-through system was switched off increased in an associated fashion, since the passive attenuation of the earplug was constant. In noise fields up to 100 dBA varying the level of pass-through provided good levels of variation in noise reaching the ear (i.e. good variable attenuation). However, in the highest ambient noise (110 dBA ), the OASPL in the earcanal with the pass-through system at the minimum and mid-positions was similar to that of the earplug in its passive state, since the electronics limit the absolute levels of noise reaching the ear to a safe level.

Whilst the tactical earplug appears to offer a means of varying the level of protection afforded it is not possible with current measurement techniques to calibrate the pass-through to provide absolute levels of attenuation and, hence, to be of practical use in a double protection system at this time.

## EFFECT OF DOUBLE HEARING PROTECTION ON NOISE AT EAR

In order to illustrate the impact of the choice of earplug device used in a double protection system the helmet+Mini-CEP and helmet+Omara figures were applied to noise dose data collected for military aircrew.

There are a number of aircraft for which the attenuation provided by the standard aircrew helmet when worn alone is insufficient to meet the legislative requirements of CNAWR. The daily personal noise exposure was calculated for a number of these aircraft environments and the shortfall in the levels of attenuation required to meet CNAWR was determined and is shown in column 2 of Table 1. Column 3 of the table provides the attenuation afforded by the helmet+Mini-CEP over and above the attenuation of the helmet itself. The final ($4^{th}$) column of the table indicates the level of additional protection, over and above that required to meet the regulations. This additional protection was, for the majority of aircraft, quite high and has the potential to mask the wearer's detection of noise and audio cues generated in the immediate environment and may cause feelings of isolation and reduce situational awareness.

**Table 1:** Calculated attenuation required to meet CNAWR for 12 Aircraft and additional attenuation provided by double protection with the Mini-CEP

| Aircraft type | Additional Protection Required | Protection provided by Mini-CEP component | Overprotection/ Shortfall |
|---|---|---|---|
| 1 | 9.0 | 19.9 | 10.9 |
| 2 | 8.0 | 13.8 | 5.8 |
| 3 | 2.4 | 22.8 | 20.4 |
| 4 | 10.2 | 19.8 | 9.8 |
| 5 | 8.2 | 19.8 | 15.8 |
| 6 | 10.0 | 19.5 | 10.5 |
| 7 | 4.0 | 19.5 | 6.5 |
| 8 | 9.0 | 21.9 | 11.7 |
| 9 | 13.0 | 22.1 | 16.9 |
| 10 | 10.2 | 21.2 | 10.8 |
| 11 | 5.2 | 20.5 | 20.5 |
| 12 | 10.4 | 21.0 | 21.0 |

Further work is needed to understand whether this high level of additional protection provided by the helmet+Mini-CEP constitutes overprotection and poses a safety risk for military aircrew.

The same calculations were performed for the Omara earplug fitted with three different filters when worn as a double hearing protection system. These results are shown in Table 2.

Column 2 provides the additional protection required to meet the CNAWR for the same 12 aircraft as in Table 1. The additional protection afforded by the Omara earplug fitted with the LD24 filter over that afforded by the helmet alone is provided in column 3. The level of over-protection (positive values) or the shortfall in protection (negative values) that this affords is provided in column 4. These calculations are repeated in columns 5 and 6 for the earplug fitted with the LD14 filter and in columns 7 and 8 for the earplug fitted with the LD10 filter. Those cells highlighted in red indicate that the earplug does not provide sufficient attenuation to meet the CNAWR, even when fitted with the most highly attenuating filter. However, it is possible that a solid version of the plug may satisfy the requirements for these aircraft. **Table 2:** Calculated Attenuation Required to meet CNAWR for 12 Aircraft and additional attenuation provided by double protection with the Omara earplug fitted with three different filters.

**Table 2:** Calculated attenuation required to meet CNAWR for 12 Aircraft and additional attenuation provided by double protection with the Omara earplug fitted with three different filters

| Aircraft type | Additional Protection Required | Protection provided by LD24 plug | Over protection /Shortfall LD 24 | Protection provided by LD14 plug | Over protection /Shortfall LD 14 | Protection provided by LD10 plug | Over protection /Shortfall LD 10 |
|---|---|---|---|---|---|---|---|
| 1 | 9.0 | 11.5 | 2.5 | 9.3 | 0.3 | 6.8 | -2.2 |
| 2 | 8.0 | 6.2 | -1.8 | 3.9 | -4.1 | 5.7 | -2.3 |
| 3 | 2.4 | 14.5 | 12.1 | 10.7 | 8.3 | 7.0 | 4.6 |
| 4 | 10.2 | 9.9 | -0.3 | 8.9 | -1.3 | 10.2 | 0.0 |
| 5 | 8.2 | 9.9 | 1.7 | 8.9 | 0.7 | 10.2 | 2.0 |
| 6 | 10.0 | 7.6 | -2.4 | 6.4 | -3.6 | 7.1 | -2.9 |
| 7 | 4.0 | 7.6 | 3.6 | 6.4 | 2.4 | 7.1 | 3.1 |
| 8 | 9.0 | 11.0 | 2.0 | 9.4 | 0.4 | 7.3 | -1.7 |
| 9 | 13.0 | 11.4 | -1.6 | 10.0 | -3.0 | 8.2 | -4.8 |
| 10 | 10.2 | 10.4 | 0.2 | 8.6 | -1.6 | 7.1 | -3.1 |
| 11 | 5.2 | 9.5 | 4.3 | 8.6 | 3.4 | 9.2 | 4.0 |
| 12 | 10.4 | 10.2 | -0.2 | 9.2 | -1.2 | 10.3 | -0.1 |

The cells highlighted in yellow indicate that the required levels of additional protection is met for the Omara earplug fitted with that particular filter, when worn with the helmet as part of a double hearing protection system. The filter best suited to meet the needs of a particular aircraft will be dependent on the spectral characteristics of the aircraft cockpit noise and whether dominant tonal components fall below 250Hz. This type of device, therefore, offers the ability to accurately match the attenuation requirements of each individual platform.

## CONCLUSIONS

Double hearing protection systems appear to offer the simplest solution to reduce hearing damage risk and enable employers to meet the legislative requirements. However, due to the interaction between the earplug, the earmuff and the head and torso, the attenuation afforded by the double protection system must be considered as a whole and must be measured using human participants.

For military application the choice of earplug and earmuff must be considered carefully to ensure that the level of overall protection afforded is commensurate with operators requirements and the balance between sufficient protection and overprotection is achieved.

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# MP3 player listening sound pressure levels among 10 to 17 year old students[1]

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## INTRODUCTION

Our lab has recently reported that, if played at maximum volume settings for prolonged durations, portable digital audio players are capable of causing hearing impairment among users (Keith et al. 2008). At maximum volume settings, the sound level output ranged from 101 to 107 dBA, which, after 3 to 12 minutes, would exceed the most protective occupational noise exposure level limits set in Canada, of 85 dBA Lex(8hr) with a 3-dB exchange rate (Canadian Centre for Occupational Health and Safety 2009).

We also reported that measured sound levels from portable digital audio players among a small sample of 28 university subjects ranged from 55 to 85 dBA (McNeill et al. 2010). When considered in combination with self-reported duration of daily usage, none of the subjects used their device at a level that exceeded an 85 dBA Lex(8hr) under typical listening conditions. Nevertheless, self-reported tinnitus was associated with measured volume output levels and how long people owned their device.

The primary objective of this study was to build upon our previous work by investigating whether subjects listen to their devices at sound levels that would increase their risk of hearing impairment when their duration of listening has been taken into account.

## METHODS

### Subjects

This study included 248 subjects aged 10 to 18 (110 males, $\bar{x}$ = 12.75, *SD* = 1.74; 138 females, $\bar{x}$ = 12.45, *SD* = 1.67), recruited from within Ottawa public and private schools. A total of 29 subjects (17 males, 12 females) had to be removed from the

[1] The full manuscript with the same title has been submitted to the *Journal of the Acoustical Society of America* 03/28/2011

analysis because they did not: i) use headphones (4 males, 3 females); ii) provide listening durations (2 females); have a device with them at the time of testing (12 males, 7 females); and iii) one male had to be removed because he was above the age of 17 at the time of testing. The current analysis is therefore based on 219 subjects aged 10 to 17 (93 males, $\bar{x}$ = 12.87, *SD* = 1.69; 126 females, $\bar{x}$ = 12.55, *SD* = 1.69) from 15 participating private and public schools. The participation rate was 11 %. This low participation rate may be related to distribution of consent forms by hand from teacher to student to parent, and the need for consent from both student and parent. This study was approved by the human research ethics board at Health Canada. Data collection took place between October 2009 and May 2010.

### Sound level measurements and Lex calculation

A detailed characterization of the sound level measurements has previously been documented by Keith et al. (2008) and McNeil et al. (2010).Using a Bruel & Kjaer type 4128 HATS, two 32s measurements of $L_{Aeq}$(32s) were taken for both typical and maximum settings. The daily exposure level, Lex(8hr), was calculated from subjects' self-reported duration of use per week (in hours), using a 3 dB exchange rate. Background sound level measurements were between 40 and 52 dBA.

Initially, sound level recordings were taken from two of the subject's favourite songs at their typical listening setting. For each measurement, subjects were instructed to load one of their favourite songs on their MP3 player and set their device at the level they would normally or typically listen to it. At this point subjects listened through both earphones in the quiet (≤ 52 dBA) testing environment. Then, subjects with earbuds or insert earphones were instructed to place their right earbud/earphone on the manikin while keeping the left in their own ears. They then listened to the output of the manikin using an appropriately equalized (ISO 11904-2 (2004)) Koss ESP950 circumaural electrostatic monitoring headphone on their right ear. Subjects were then asked to adjust the fit of their right earbud on the manikin until the song sounded the same in the Koss monitoring headphones and their left earbud. By implementing this procedure, to the best of the subject's ability, the sounds measured by the manikin matched the earphone output from their MP3 players.

After measuring two songs at their typical listening setting, subjects played two more songs at their maximum volume setting. The maximum volume measurements were carried out identically to the typical volume measurements described above, with one difference. The subjects marked their maximum volume setting on an 82 mm x 7 mm horizontal bar labelled 0 to 100. They then set their MP3 player to that volume setting. A volume based on visual recollection was expected to provide an estimate of maximum listening volume, without being biased by the background noise at the time of testing.

### Statistics

Sound level results, in tables include the mean ($\bar{x}$), medians (*M*), minimum value, maximum value and the associated interquartile range (IQR; 75$^{th}$ percentile minus 25$^{th}$ percentile). Statistical differences between group means were analyzed using the *t*-test, with an alpha level of 0.05. Assumptions for the t-test were verified using the Anderson-Darling test for normality and Bartlett test for equal variance between groups. When assumptions of normality and equal variance were not satisfied, the Kruskal-Wallis (KW) $\chi^2$ non-parametric test was applied. Proportional differences in groups were tested using chi-square test of independence, with Yates correction for 2x2 contingency tables. The Pearson correlation coefficient was used to assess the linear relationship between two variables. When the assumptions of bivariate normality and linear relationship were not satisfied for the variables, then the non-parametric Spearman correlation coefficient was applied.

RESULTS

## Portable digital audio player use

Of the 219 subjects in the final analysis, 216 (98.6 %) specified the type of device they used. Further 172 subjects (78.5 %) specified the type of headphones/earphones used (see Table 1).

**Table 1:** Frequency and percentage of different types of portable digital audio players and earphones/headphones

| Type of portable digital audio player | Frequency (%) N=219 | Reported type of earphones/headphones | Frequency (%) N=219 |
|---|---|---|---|
| Apple iPod Nano | 87 (39.7) | Earbuds | 89 (40.6) |
| Apple iPod Classic | 55 (25.1) | Insert canal | 44 (20.1) |
| Apple iPod Touch | 22 (10.0) | Circumaural | 12 (5.5) |
| Apple iPod Shuffle | 7 (3.2) | Supra-aural | 5 (2.3) |
| Apple iPhone | 4 (1.8) | Supra-aural and earbuds | 12 (5.5) |
| Sony PSYC | 4 (1.8) | Supra-aural and insert canal | 1 (0.5) |
| Other | 34 (15.5) | Circumaural and earbuds | 3 (1.4) |
| Do not know | 3 (1.4) | Circumaural and insert canal | 5 (2.3) |
| Missing | 3 (1.4) | Other | 1 (.5) |
| | | Missing | 47 (21.5) |

The history of MP3 player use varied from 1-4 weeks (<1 %) to more than 5 years (11 %). About 5 % reported using their device for less than 6 months and 4 % indicated between 6 months and 1 year. Fifty-one percent of the subjects used their device between 1 and 3 years and 28 % used it between 3 and 5 years. The mean daily usage ranged from 0.014 hours to 12 hours and was not statistically different between males ($\bar{x}$ = 1.13, *SD* = 1.35) and females ($\bar{x}$ = 1.06, *SD* = 1.71) (KW $\chi_1^2$ =3.17, p=0.0751).

## Measured equivalent free-field sound levels

Sound level results are provided in Table 2 for all subjects and for males and females separately. When typical sound levels were considered with the derived duration of daily use, 3.2 % of the subjects surpassed the most stringent and common occupational noise limit in Canada of 85 dBA Lex(8hr) with a 3 dB exchange rate. If it was assumed that subjects' total listening time was done at their maximum sound level settings, 8.7 % would exceed this limit. The average self-reported maximum volume settings measured about 7 dBA higher than subjects' typical volume settings. The correlation between the two settings was 0.805, $p < .0001$.

## Personal variables

Gender was examined as a potential personal variable that could influence the listening habits of users of MP3 players. On average, males preferred to listen to their iPods or MP3 players at slightly higher volume settings compared to females for 3 of the 4 measured values, Leq(32s) maximum condition (KW $\chi_1^2$ =4.37, p=0.0366), Lex(8hr) typical (KW $\chi_1^2$ =5.04, p=0.0247) and Lex(8hr) max (KW $\chi_1^2$ =5.68, p=0.0171) (see Table 2). There was no statistical difference between the percentage of males and females listening to their iPods or MP3 players greater than 75 dBA or 85 dBA, whether for Leq(32s) or Lex(8hr).

**Table 2:** Energy average sound levels (dBA) for typical and maximum sound level settings and calculated time-weighted average eight hour exposure level, Lex(8hr)

| | n[a] | Mean | SD[b] | SEM[c] | Min[d] | Max[e] | Median | IQR | percent above (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 75 dBA | 85 dBA |
| All subjects | | | | | | | | | | |
| Leq(32s)[f] Typ | 219 | 68.6 | 11.5 | 0.8 | 45 | 113 | 68 | 15 | 26.0 | 5.0 |
| Leq(32s)[f] Max | 219 | 76 | 12.9 | 0.9 | 49 | 113 | 76 | 18 | 52.1 | 21.5 |
| Lex(8hr) Typ | 219 | 57.0 | 14.0 | 0.9 | 29 | 110 | 56 | 18 | 9.6 | 3.2 |
| Lex(8hr) Max | 219 | 64.3 | 15.7 | 1.1 | 30 | 110 | 65 | 22 | 22.4 | 8.7 |
| Females | | | | | | | | | | |
| Leq(32s) Typ | 126 | 67.8 | 12.2 | 1.1 | 45 | 113 | 66 | 15 | 22.2 | 6.4 |
| Leq(32s) Max | 126 | 74.5 | 13.8 | 1.2 | 49 | 113 | 74 | 19 | 46.8 | 18.3 |
| Lex(8hr) Typ | 126 | 55.7 | 14.9 | 1.3 | 29 | 110 | 54 | 18 | 11.9 | 4.0 |
| Lex(8hr) Max | 126 | 62.5 | 16.8 | 1.5 | 30 | 110 | 62 | 24 | 18.3 | 10.3 |
| Males | | | | | | | | | | |
| Leq(32s) Typ | 93 | 69.6 | 10.5 | 1.1 | 50 | 100 | 69 | 16 | 31.2 | 3.2 |
| Leq(32s) Max | 93 | 77.7* | 11.5 | 1.2 | 51 | 105 | 78 | 14 | 59.1 | 25.8 |
| Lex(8hr) Typ | 93 | 58.8* | 12.4 | 1.3 | 35 | 91 | 58 | 20 | 6.5 | 2.2 |
| Lex(8hr) Max | 93 | 66.8* | 13.7 | 1.4 | 35 | 101 | 69 | 17 | 28.0 | 6.5 |

* Significant difference to corresponding groups from females, $p < 0.05$. [a]n, the number of subjects; [b]SD, standard deviation; [c]SEM, standard error of the mean; [d]Min, minimum subject listening level; [e]Max, maximum subject listening level; [f]Leq(32s), the average of two 32 second sound level measurements at subjects' typical (Typ) and maximum (Max) volume settings

## DISCUSSION

Based on the sound levels associated with typical usage in our study: i) nearly 74 % of the subjects listened at levels less than 75 dBA $L_{eq}$ which would pose no known risk to hearing even if listened to for 8 hours per day, ii) 9.6 % exceeded 75 dBA Lex(8hr), and 3.2 % were above a damage-risk criterion level of 85 dBA Lex(8hr) with a 3 dB exchange rate. If we made the cautious assumption that subjects listened maximum volume settings for their entire self-reported listening duration, 22.4 % of them exceed 75 dBA Lex(8hr) and 8.7 % would yield a Lex(8hr) exposure level above 85 dBA. These values seem to be far less than that reported by most others (Williams 2005; Kumar et al. 2009; Ahmed et al. 2007). It is plausible that in our study the quiet classroom conditions resulted in subjects selecting a typical volume setting that was lower than it would have otherwise been if background noise levels were higher. Background noise levels may bias the listening levels. To reduce the influence of the low background noise on measurement of maximum listening levels, the subjects first placed a line through a bar intended to represent their maximum volume conditions. They then set the volume indicator on their device to the same location. However, we were unable to determine what fraction of daily listening duration was at these worst-case listening levels. Subjects may have had difficulty recalling their maximum volume settings. Furthermore, the issues of social desirability, which occurs when subjects respond as they think they "should" or how "good" people would, could have been involved. Subjects may not have wanted to play their devices loudly in front of researchers. These shortcomings are the same as those we reported in McNeill et al. (2010) and will continue to be a source of uncertainty in future studies that follow the same methodology.

## CONCLUSIONS

1. Under the conditions of the current study, the percentage of subjects with exposures above 85 dBA, Lex(8hr) was about 3 % and 9 %, using the measured typical and maximum sound levels, respectively, when both were combined with self-reported typical listening durations.
2. Tightness of fit, the influence of background sound levels and the proportion of time subjects listen to their device at their worst-case volume settings are all variables that need to be more carefully examined with questionnaires. This will improve the estimation of risk that MP3 player usage may pose to hearing.
3. Despite efforts to control important parameters, the magnitude of uncertainty in the current study was large enough to affect results and could, therefore, affect any conclusions drawn from these results. To improve the assessment of potential risks that may be associated with use of MP3 players, in future studies, further control and systematic characterization of the uncertainties will be needed.

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# Driving change for the better in occupational health surveillance for noise induced hearing loss

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## INTRODUCTION

As the enforcing authority for the Control of Noise at Work Regulations 2005 (HSE, 2006) in Great Britain, the Health and Safety Executive (HSE) has responsibility for producing guidance and providing advice to assist employers in meeting their legal duties under this legislation. This includes providing guidance and advice for employers where they need to meet a duty under Regulation 9;

*'If the risk assessment indicates that there is a risk to the health of his employees who are, or are liable to be, exposed to noise, the employer shall ensure that such employees are placed under suitable health surveillance, which shall include testing of their hearing.'*

Health surveillance is a programme of systematic health checks to identify early signs and symptoms of work-related health in order for actions to be taken to prevent ill health progression and protect workers. The results of health surveillance are fed back to inform the risk assessment, risk management and review of control processes.

Current guidance on noise health surveillance details regular hearing checks via audiometric testing as the recommended method (HSE 2006). This method involves presenting sounds of fixed frequencies and varying intensities to the ear. Pure Tone Audiometry (PTA) is a subjective, behavioral measurement of hearing threshold, as it relies on patient response to pure tone stimuli. PTA involves presentation of pure tones to each ear at specific frequencies, so that the configuration of a hearing loss can be identified.

Awareness and control of noise at work has moved on immensely since the early 1980's, when the Medical Series guidance note; MS26 "A guide to audiometric testing programs" (no longer in circulation) was first published, yet we are still using the same method for health surveillance. PTA has come under some criticism in its limitations as a tool for occupational health surveillance as follows;

- The method only detects hearing damage at a level where damage is significant enough to affect the ability to hear pure tones. This damage is permanent and irreversible and may have been accumulated over many years of exposure alongside age related deterioration.
- There is a time lag between hazardous exposure and damage being detected, causing difficulties in the method being able to provide a timely preventative approach to revisiting the risk assessment and controls.
- The methodology requires strict test conditions in order to ensure quality of the results. This also compromises repeatability, which is an essential element of a health surveillance tool. That is in order to make judgements on effects of workplace exposures comparisons are made with previous test results.
- The test is subjective and requires cooperation from the individual being tested to respond to the pure tone signals being presented. Therefore uncooperative or untrustworthy individuals will not produce useful results.

HSE is interested in exploring options to improve the standards of noise health surveillance to assist dutyholders in meeting the aspirations of a robust occupational health surveillance model that enables early detection of signs or symptoms of ill health and useful and timely data that can enable preventative actions in reducing irreversible noise induced hearing damage.

One of the most promising advances in audiological testing has been the discovery of otoacoustic emissions (OAE) testing. This method has widespread application as a simple, non-invasive, test for hearing defects in newborn babies and in children who are too young to cooperate in conventional hearing tests. Many western countries now have national programs for the universal hearing screening of newborn babies. OAEs are responses generated by outer hair cells of the inner ear when stimulated by sound transmitted via a small microphone placed in the ear canal via an ear plug. OAEs have been widely shown to be depressed by noise exposure. HSE are interested in working closely with researchers, manufacturers, the audiological and occupational health community in fully exploring the potential of this method for application in occupational health surveillance.

## METHODS

Following years of interest in the potential of OAE testing in occupational health, HSE decided it was timely to take action to make a concerted effort to achieve consensus on the way forward for research and practical application of this test method. An international expert symposium on the usefulness of OAE testing in occupational health surveillance was arranged to take place in Manchester on the 8-9th February 2011. This event managed to attract the attention of worldwide leading researchers and practitioners in this field. A list of participants is given in Table 1.

**Table 1**: List of participants attending International Expert Symposium on the usefulness of OAE Testing in Occupational Health Surveillance, 8-9th February 2011, Manchester UK

| | |
|---|---|
| Anil Adisesh | Health & Safety Laboratories, UK |
| Stephen Archer | Occupational Health, Metropolitan Police, UK |
| Borka Ceranic | St Georges Hospital, London, UK |
| Alison Codling | Health & Safety Laboratories, UK |
| Clare Forshaw | Health & Safety Executive, UK |
| David Fox | Health & Safety Laboratories, UK |
| Hiske Helleman | Academic Medical Center, Netherlands |
| Agnès Job | Centre de Recherches du Service de Santé des Armées (CRSSA), France |
| David Kemp | The University of Central London, Ear Institute, UK |
| Mark Lutman | Institute of Sound and Vibration Research, University of Southampton |
| Lynne Marshall | Naval Submarine Medical Research Laboratory, Groton, Connecticut |
| Arturo Moleti | Dipartimento di Fisica - Universita' di Roma Tor Vergata |
| Annie Moulin | French National Center for Research (CNRS) |
| Brian O'Reilly | Occupational Health, Metropolitan Police, UK |
| Kerry Poole | Health & Safety Laboratories, UK |
| Dil Sen | Health & Safety Executive, UK |
| Rob Shepheard | Consultant Audiologist, SPIRE Hospital Norwich, UK |
| Renata Sisto | Italian National Institute of Occupational Safety and Prevention (ISPESL) |

The aims of the event were

- to discuss the potential of OAE for use in occupational health surveillance,
- to explore the current scientific position,
- to discuss the barriers involved in advocating this new method,
- identify the gaps in understanding and
- decide where do we go next.

Following a series of presentations by the participants on their areas of interest and expertise in this area the group present at the meeting were invited to discuss and debate their experience and scientific knowledge based around a series of key issues presented by HSE at the meeting. These key issues were developed from a review of the literature undertaken by HSE and the Health and Safety Laboratory (HSL), which identified relevant gaps in the research evidence (unpublished). These gaps were identified in the context of what HSE expect OAE to deliver within an occupational health surveillance program.

The facilitated session aimed to reach consensus amongst the participants on the relevant issues to the usefulness of OAE testing in occupational health surveillance based on scientific evidence and expert agreement. Participants present were asked to agree points of consensus where they felt there was strong scientific evidence. The key issues tabled for discussion at the symposium facilitated session are given in Table 2.

**Table 2:** Key Issues Tabled for Discussion at the Symposium

| |
|---|
| • What is the relationship between OAE and NIHL? |
| • **Relevance of OAE testing for use in occupational health surveillance** |
| • What qualifies as an acceptable OAE measure? |
| • What change in emission is needed to indicate abnormality? |
| • Distortion Product vs Transient Evoked OAE measures |
| • What are the most appropriate test parameters? |
| • **What is the practical value/added benefit?** |
| • Are there any limitations to this method that would reduce its usefulness in health surveillance? |
| • **Gaps/Barriers. Taking the Work Forward** |

The following report documents the key areas of discussion relevant to the aims of the session and the consensus points agreed. Where consensus was not reached this does not mean there is no evidence or that there is no support for usefulness in this area. It reflects a lack of consensus on strength of evidence amongst the group, a need for further research, or no clear understanding at this time.

## RESULTS

The following provides a summary of the key points discussed by the group under the main headings given in Table 2 and the consensus points reached.

### What is the relationship between OAE and Noise Induced Hearing Loss?

The facilitated session first considered the general concept of using OAE within an occupational health setting. Through discussion it soon became apparent that there is a need for agreed common terminology in discussions and reporting in this area.

The group concluded that the exact purpose of the role of OAE testing within an occupational health surveillance program needed to be established before usefulness and applicability could be agreed. For example, there was a lack of clarity as to whether health surveillance aimed to follow grouped data to identify ‘at risk’ groups or whether the main purpose was to longitudinally follow individuals for the progression of hearing loss or damage.

There was some discussion on what health surveillance for noise induced hearing loss (NIHL) aims to achieve. Table 3 summarizes the thoughts of the group on the strength of evidence for OAE use under a number of potential aims of occupational health surveillance.

It was agreed that the evidence base for the usefulness of OAE is different for monitoring the effect of noise exposure in a health surveillance program on individuals and groups of workers. The participants agreed that there is strong evidence to support the use of OAE testing to longitudinally monitor groups of similarly exposed individuals and to identify ‘at risk’ groups at an early stage.

‘At risk’ was found to be difficult to define as the process of damage to outer hair cells picked up by OAE testing and the resulting hearing loss eventually picked up by PTA is not fully understood. However, it was felt there could be confidence that we are identifying subclinical changes to outer hair cells as a result of exposure to noise, which we know is likely to have an effect on hearing ability in the future.

**Table 3:** Summary of the Symposium Delegates views on evidence for the usefulness of OAE in Occupational Health Surveillance

| **Aim of occupational health surveillance** | **Evidence for relevance of OAE supported?** | **Comments** |
|---|---|---|
| Prevention of damage | Possible | |
| Feedback to employer on effectiveness of controls | Yes with grouped data strong support | |
| Individual management of health effects | A possibility but, not strong evidence yet | |
| Identification of clinical damage/diagnosis | Evidence is sufficiently strong, depending on the specific diagnostic task and the population under test | |
| Biomarker of potential health effect | Yes, depending on the population and diagnostic task | |
| Biomarker of exposure | Yes, depending on the population and diagnostic task | |
| Identify effect of exposure for all workers? | No | Only useful when good OAEs can be measured |

The evidence base supports use of OAE testing for individuals with good OAE emissions at test. As long as there are demonstrable emissions at a baseline test then OAE testing has value for monitoring individuals.

A consensus view on how a health surveillance program would be structured was to set a baseline with OAE and PTA. Following this periodical monitoring with OAE and only PTA where OAE produced ‘abnormal’ results i.e. large changes in emissions. We are not yet at a stage where we would not expect PTA to be a part of a health surveillance program for NIHL.

### Relevance of OAE for use in occupational health

- There is evidence for a direct correlation between OAE and NIHL, BUT this is not a 1:1 relationship. This is due to the impact of non noise related issues on other parts of the auditory pathway.
- There is evidence for a well-established causal link between OAE and NIHL in groups of individuals via histopathological studies, animal studies, cross-sectional studies and empirical/anecdotal evidence.
- The evidence base supports use of OAE testing for individuals with good OAE emissions at test
- OAE reflect outer hair cell damage and outer hair cells are the most sensitive auditory function to noise damage
- OAEs can therefore have an important role as an earlier indicator of damage/effect of noise exposure
- OAEs also have a role in identifying temporary threshold shift (TTS) which can be very useful in demonstrating the effect of noise exposure. There is evidence that permanent nerve damage can accumulate from TTS
- There is a need for the development of an agreed standard operating protocol specific to why the test is being performed.

### What qualifies as an ‘acceptable’ OAE measure?

In response to this question the participants again referred to the need to understand exactly what we want the test to do. There is an issue of reproducibility of results when emissions are near the noise floor. However, the noise floor is not the sole determinant of a good recording. The key aspect would be to achieve a good Signal to Noise Ratio (SNR). The group considered that it would be difficult to monitor results longitudinally if the testing program began with an emission near the noise floor as this erodes reproducibility. Conversely, the results would be considered significant if there was a sudden change from a strong emission moving towards the noise floor. As with PTA, quality assurance issues are important when using the equipment but if good signals were correlated with good thresholds then you could be confident of reliable measurements.

### What change in emission is needed to indicate abnormality?

The participants acknowledged that there was difficulty in providing an agreed validated reference point for consistent and standardized advice in this area due to the lack of a normative reference population data.

### Distortion Product OAE vs Transient Evoked OAE Methodology

Neither test covers all the frequencies of interest for NIHL. Distortion Product OAE (DPOAE) has strengths in that recent research has shown you can usefully separate the more specific frequency components. The strengths of Transient Evoked OAE (TEOAE) testing are that both click or Maximum Length Sequence (MLS) versions of the methods test a large proportion of the cochlea simultaneously. The group concluded that current evidence supports a combination of both DP and TE OAE methods following each other as a fast and effective way of OAE testing.

### What are the most appropriate test parameters?

The participants considered this question but agreed that the most appropriate test parameters would depend on what you want the test to do i.e. different test parameters would be required when testing for vulnerability of future hearing loss ('at risk') and looking for mild hearing loss.

It was agreed that care would need to be invested in the testing procedure to ensure good quality emissions and a range of frequencies should tested and an average taken. DPOAE is currently the method with the most evidence to support its application in this field. However, further research may develop stronger evidence for other methods. There is a need for the development of an agreed standard operating protocol specific to why the test is being performed.

The group noted a need for commercially available equipment geared at occupational use to facilitate research and practical application. The present trend in clinical applications of OAE diagnostics is to propose user friendly instruments based on low frequency resolution DPOAE or conventional TEOAE recordings. Such instruments do not fully exploit the diagnostic potential of OAE. Participants discussed high spectral resolution DPOAEs and Stimulus-Frequency OAEs (SFOAES) as promising techniques for detecting quality frequency specific OAE response

### Practical value of OAE. Added benefit to PTA program alone

- Objectivity
- Specific to outer hair cell damage which is the most vulnerable of auditory pathway to high noise
- Detects small changes in the cochlea or in the middle-ear functioning
- Somewhat less stringent test environment than PTA, although this remains an important test in a robust health surveillance regime
- Quick
- 3 stage approach
    - Baseline PTA & OAE
    - Interval OAE monitoring
    - PTA as and when problems identified
- Can alert to other auditory health conditions affecting the cochlea or middle ear.
- Key tool for motivational and educational purposes.
- Can reduce employer liability
- OAE has a key role as part of holistic approach to hearing conservation
- The disincentive to investment in advance of PTA techniques is due to the subjective nature of the test and the time factor in achieving increased sensitivity in PTA testing.

### Limitations for application in occupational health surveillance

- Lack of normative data
- Training of technicians is needed, particularly on probe fit and blocking
- If there is a change in OAE is it necessary to eliminate middle ear cause
- Tympanometry should be undertaken, particularly at a baseline OAE test (this is more important when setting up an OAE program of test than for PTA)
- Need to ensure no occlusion of the ear canal

- Age may be an issue. However, if emissions are strong enough to allow room for decline to be detected then no problem
- Consensus that under the age of 40 are likely to provide ‘cleaner’ data
- Hearing threshold levels higher than 30-40dB cause the OAE response to fall close to the noise floor, making the SNR too low to achieve accurate diagnostic information. However, as OAEs are frequency specific, subjects affected by severe hearing loss at certain frequencies, may still have sufficient OAE at other frequencies to be able to usefully monitor effects of noise exposure here.
- The different temporal behavior of temporary shifts in OAE levels and audiometric thresholds following exposure to high impulse noise levels suggest that time after exposure should be considered a key parameter to be controlled in health surveillance
- OAEs depends on stimulus level and test parameters so these need tight control and agreed consistency to achieve comparable results

### Gaps/Barriers and Taking the work forward

There was an agreed need to coordinate the development of a validated normal distribution of OAEs. The practicality of achieving this raised the issue that a standardized test methodology would need to be developed in the first instance. An agreement on standard terminology is needed and lack of commercial availability of equipment designed specific for application in occupational health is a current barrier.

In addition to a number of practical barriers there is also the need to influence behavioral change amongst all players involved in occupational health including employers, workers and occupational health professionals to bring about acceptance of the usefulness of the method.

## CONCLUSION

There was consensus on many aspects of OAE use in occupational health surveillance. The event has stimulated ideas for collaboration amongst the participants and an electronic forum has now been set up for sharing relevant data to provide a more robust evidence base and the potential for pooling of data for future research is being explored.

- The group agreed that there is strong evidence to support the use of OAE testing to longitudinally monitor groups of similarly exposed individuals and to identify ‘at risk’ groups
- There is evidence of the usefulness of OAE in the early detection of ‘at risk’ groups following noise exposure from ‘normal hearing’ populations.
- The evidence base supports OAE use in individuals who have clear emissions at recruitment into the program
- A combination of both DP and TE OAE methods following each other promises a fast and effective way of OAE testing at this time
- The noise floor should be as low as practicable but should not restrict testing of individuals who show good SNR.

Next steps for the core group working in collaboration were to;

- agree some common terms and their meaning in respect of discussions and reporting in the use of otoacoustic emissions testing and occupational health.

- facilitate collation of normative data as a reference point to establish age related 'norms'.

Other issues which need addressing are

- The need for an internationally agreed standard operating protocol for OAE testing in occupational health situations.
- The need for commercially available equipment geared at occupational use to facilitate research and practical application.

The symposium has provided a platform upon which we need to build the science in areas where there is doubt and promote the usefulness of OAE in the areas where there is belief amongst experts that there is robust evidence of potential benefit in reducing ill health caused by noise at work. The symposium has provided a forum for future collaboration and sharing of ideas amongst leading experts and HSE. It is hoped that this event has been a catalyst to inspire future research to focus on the usefulness of OAE in occupational health and also be useful in persuading the occupational health community in general of the added value OAE can bring to preventative risk management of noise health risks.

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# Hearing loss amongst classical music students

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## INTRODUCTION

Performing artists must be able to practice, rehearse, and perform safely. With respect to hearing and the "noise" of performance however, the nature of their work and the dedication of performers themselves may mean that they are placed in a difficult position when complying with new international noise at work regulations.

Since 2008, with the introduction of the new Control of Noise at Work Regulations 2005 (HSE 2005) in the UK, hearing health surveillance is necessary for any employee at risk of high noise exposure. Being at the forefront of classical music education, the Royal Academy of Music decided two years before the enforcement of the new regulations in 2008 to start the implementation of a health surveillance programme and the continuous collection of data on the hearing acuity of their music students. This paper presents the approach of the Royal Academy of Music on the issue of health surveillance for classical music students and discusses the findings of audiometric hearing tests conducted during 2006-2010.

## THE APPROACH

The Royal Academy of Music took an inclusive view whereby every new student had to compulsorily take an automated audiometric screening test during the first week of his or her studies at the Academy (Fresher's week). The testing closely followed the methodology outlined in the Control of Noise at Work Regulations. Students, prior to testing, attended a 1-hour hearing seminar, which amongst others, informed students on the purpose and procedure of the audiometric testing. To minimise the influence of any Temporary Threshold Shift (TTS), students were asked to avoid exposure to any loud noise a day before their testing and the use of ipod while travelling to the test. One-to-one interviews with each student and an otoscopic examination were used to identify any factors, which may influence the health surveillance results.

The test was based on a pure-tone air conduction Bekesy test (frequencies 500 Hz to 8 kHz) and was conducted in the audiometric soundproof booths at the Acoustic Laboratory of London South Bank University (LSBU); see Figure 1. Both booths used met the criteria given in ISO 8253-1:1989 (ISO 1989). Once the test and questionnaire was completed, each audiogram was categorised according to the Health and Safety Executive (HSE) categorisation scheme (HSE 2005); see Table 1. Students received a copy of their audiogram with the original being sent to the Academy for their records. Results were discussed individually with each student and advice has been given on protection from noise exposure, including advice on most suitable hearing protection option based on the instrument played.

**Figure 1:** Audiometric booths and audiometers

**Table 1:** HSE categorisation scheme

| *Category* | *Calculation* | *Action* |
|---|---|---|
| 1 **ACCEPTABLE HEARING ABILITY** Hearing within normal limits | Sum of hearing levels at 1, 2, 3, 4 and 6 kHz. | None |
| 2 **MILD HEARING IMPAIRMENT** Hearing within 20th percentile. May indicate developing NIHL. | Sum of hearing levels at 1, 2, 3, 4 and 6 kHz. Compare value with figures given for appropriate age band and gender. | Warning |
| 3 **POOR HEARING** Hearing within 5th percentile. Suggests significant NIHL. | Sum of hearing levels at 1, 2, 3, 4 and 6 kHz. Compare value with figures given for appropriate age band and gender. | Referral |
| 4 **RAPID HEARING LOSS** Reduction in hearing level of 30 dB or more, within 3 years or less. Such a change could be due to noise exposure or disease. | Sum of hearing levels at 1, 2, 3, 4 and 6 kHz. | Referral |

## RESULTS

As a result of the testing over the last four years, a large audiometric database has been developed, holding almost 1,300 student audiograms. By categorising the audiometric data based on the new regulations categorization scheme, it was established that 94 % of the Academy students have what is considered to be good hearing, 4.5 % of students showed a mild hearing impairment (warning) and only 1.5 % of students had poor hearing (referral); see Figure 2. Among the latter, most recorded referral cases were due to genetic hearing problems or accidents that occurred in the past and can't therefore be associated with noise induced hearing loss. For the general population, percentages for warning and referral levels are set at 20 % and 5 % respectively (see Table 1 above) indicating that young musicians have excellent hearing. Please note that another reason behind the excellent hearing results recorded among music students may be the fact that with their well-trained ears and developed sensitivity to sound/changes in pitch, music students could simply be better at detecting pure tones than general population of same age. On the other hand, noise induced hearing loss has a dose-response relationship, and hence may take up to 20 years to become apparent amongst classical musicians.

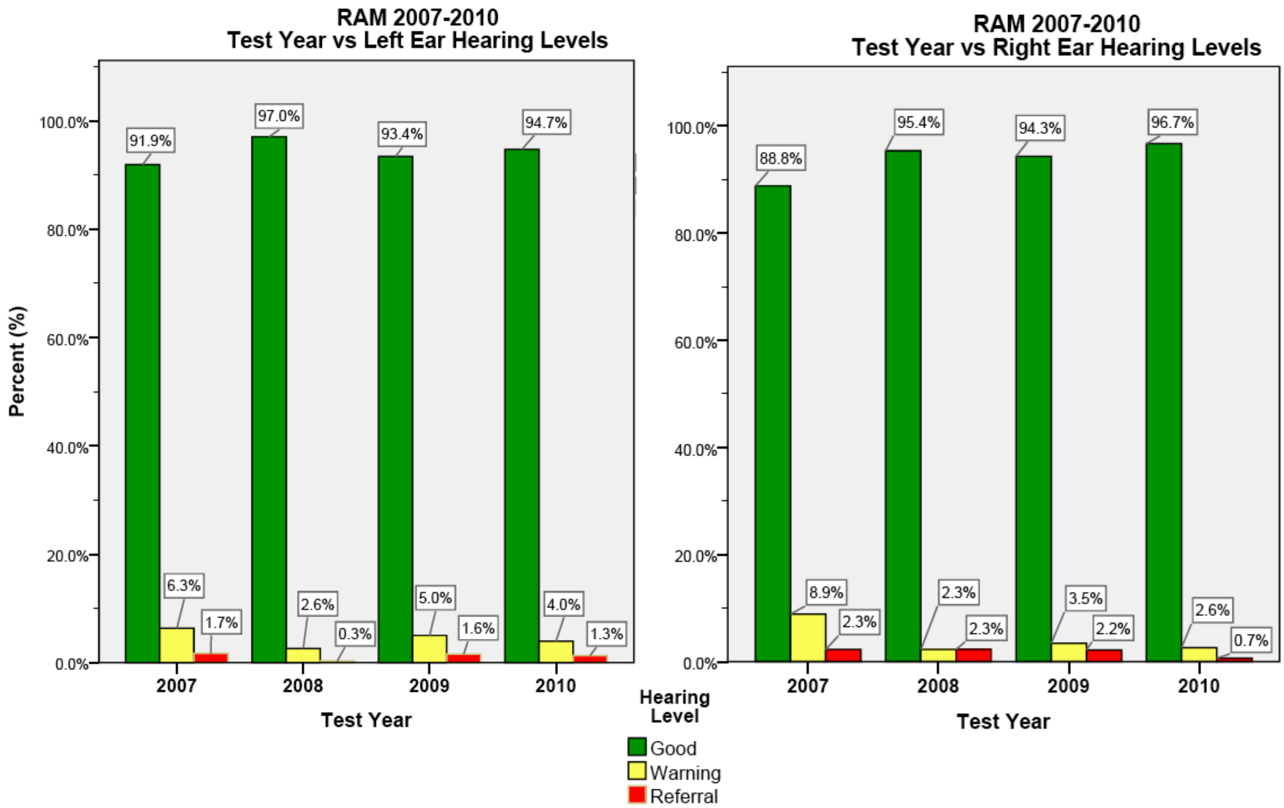


**Figure 2:** Health and safety hearing levels per test year

Results also indicated that female students tested have better hearing than male. The incidence of males with mild hearing impairment is 3 and 2 times higher than of the females for the left and right ear respectively. This may be due to the fact that male musicians tend to be involved with louder instruments, as for example brass, percussion, etc.

Due to the large number of musicians studying string instrument (27 % of students tested), highest incidence of warning and referral levels was calculated for the string instruments (25 % and 33 % respectively, both ears averaged). Second largest incidence of warning and referral levels was calculated for the brass instruments (18 % and 30 %) being followed by pianists and singers.

However, when comparing incidence of warning/referral levels within each instrument group, results show higher percentages of hearing loss among brass students. Specifically, 11 % of brass students tested have a mild hearing impairment compared to the 4 % of string and wind instrument students (averaged results from both ears; see Table 2). Highest incidence of poor hearing (referral levels) within each instrument group was once more calculated for the brass (3 %) and string (2 %) students. It must be noted that although higher percentages of both warning and referral levels were calculated for conductors and percussion/timpani students (5 % and 4 % respectively with warning, 5 % and 6 % with referral), however the total amount of students tested at those instrument groups was not statistically significant (22 and 26 students respectively). Lower incidences of hearing loss were found amongst piano, voice and musical theatre students. For detailed results on the incidence of hearing loss within each instrument group, see Table 2.

**Table 2:** Incidence of health and safety hearing levels within instrument groups (RAM 2007-2010)

| INSTRUMENT (number of tests) | Number of Stu-dents | LEFT EAR | | | RIGHT EAR | | |
|---|---|---|---|---|---|---|---|
| | | Good ( %) | Warning ( %) | Referral ( %) | Good ( %) | Warning ( %) | Referral ( %) |
| **Strings** | 349 | 93.4 | 4.3 | 2.0 | 94.8 | 3.7 | 1.4 |
| **Brass** | 96 | 86.5 | 11.5 | 2.1 | 85.4 | 10.4 | 4.2 |
| **Woodwind** | 118 | 95.8 | 4.2 | 0.0 | 94.1 | 4.2 | 1.7 |
| **Percussion/Timpani** | 26 | 84.6 | 7.7 | 7.7 | 96.2 | 0.0 | 3.8 |
| **Piano** | 215 | 96.3 | 3.3 | 0.5 | 95.8 | 3.3 | 0.9 |
| **Voice** | 174 | 96.0 | 2.9 | 0.6 | 94.3 | 3.4 | 1.7 |
| **Musical Theatre** | 123 | 96.7 | 2.4 | 0.8 | 95.1 | 3.4 | 1.7 |
| **Conductors** | 22 | 90.9 | 4.5 | 4.5 | 90.9 | 4.5 | 4.5 |

When comparing right and left ear hearing results within the strings, it is easily identified that the string players' left ears showed higher levels of hearing loss than that of their right ears. Specifically, an increase of 15 % and 20 % in the incidence of warning and referral levels respectively was calculated for the string players' left ear. This expected result is due to the fact that the most popular string instruments are asymmetric (violin/viola) with the noise being emitted at a very short distance to the left ear.

Finally, when comparing averaged hearing loss per frequency for each instrument group, a 6 kHz notch, i.e., an increase in hearing loss at the 6 kHz frequency when compared to the adjacent 4 and 8 kHz frequencies, was found. This is a sign of noise induced hearing loss also linked with musicians' noise exposure (Chasin 1998; Kähäri et al. 2001a, b; Backus & Wiliamon 2009; Lund et al. 2010). Please note that headphones used were properly placed on musician's head and have no known artefacts that could have increased thresholds at 6 kHz.

Analysis of calculated average hearing thresholds per frequency for all instrument groups tested at the Academy from 2007-2010 indicated notches at 6 kHz especially in the left ear where thresholds at 6 kHz were higher than those at 4 and 8 kHz. Most 'intense' notches, i.e. where highest differences between 4-6 and 6-8 kHz were calculated, were found for guitarists (both ears, amplified music exposure?), followed by those for string players (left ear), musical theatre singers (left ear), piano and jazz players (left ear), voice and brass (left ear).

Figure 3 shows a significant notch at 6 kHz for string players with higher thresholds at 6 kHz compared to those at 4 and 8 kHz at the left ear. A similar notch is apparent in the right ear, however with smaller differences in hearing thresholds between 4-6 and 6-8 kHz. When comparing string players thresholds to those of brass, although the 6 kHz notch is apparent in the brass players left ear, hearing thresholds at 8 kHz continue to increase at the right ear indicating a higher amount of hearing loss at high frequencies for brass players. The same, but not so significant, trend is apparent for both wind and percussion/timpani players.

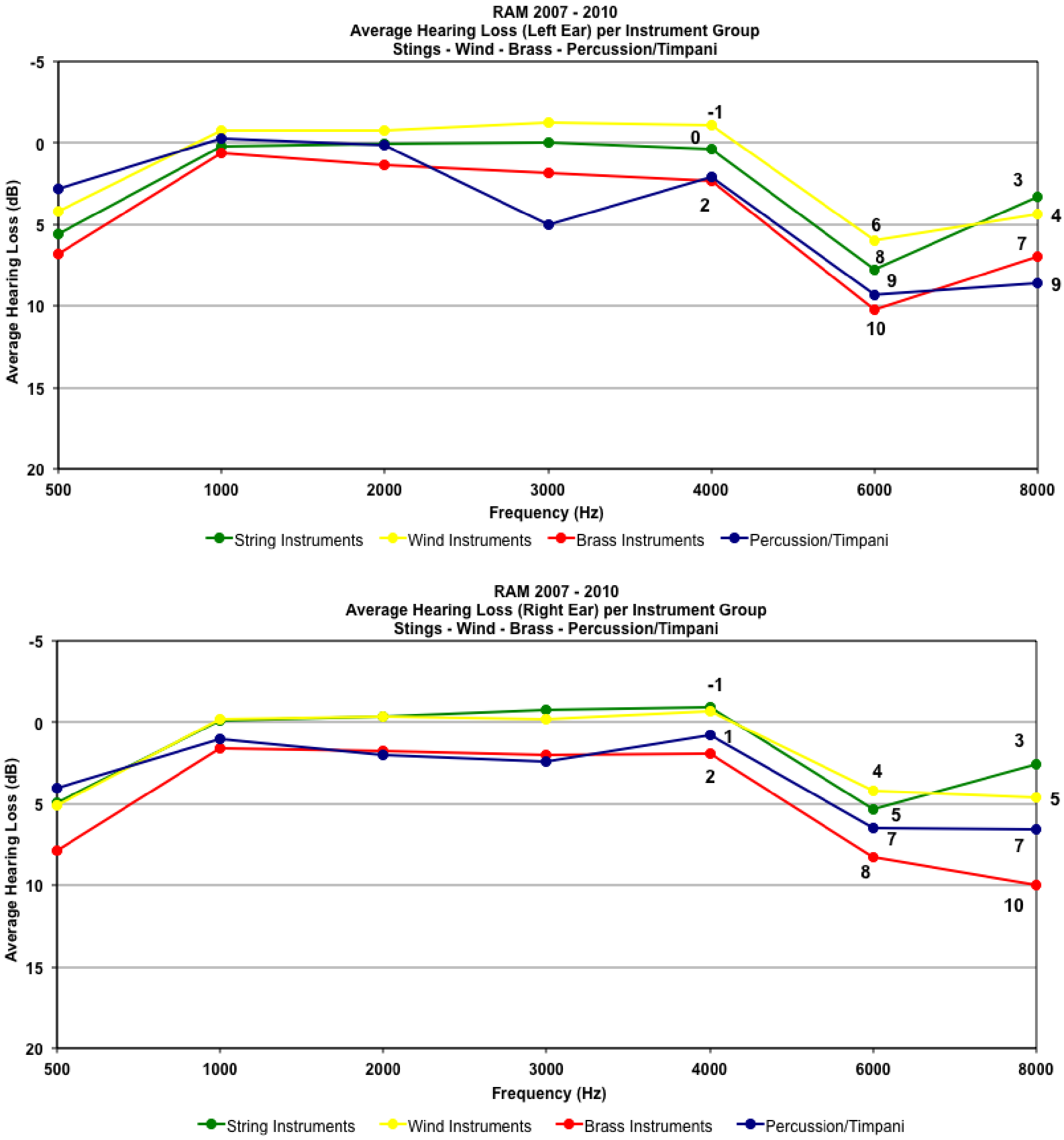


**Figure 3:** Average hearing loss per frequency for Stings, Wind Brass, and Percussion/Timpani

## CONCLUSIONS

Since 2007, the Royal Academy of Music has been following a management policy to assess the hearing acuity of the musicians at the start of their career. Results of almost 1,300 hearing tests revealed that music students have excellent hearing and less hearing problems than those of general population and same age despite their, already accumulated, hearing exposure. Highest incidence of students with mild hearing impairment or poor hearing was found among string players with highest hearing loss recorded at their left ears. However, highest percentages of hearing loss calculated within each instrument group were found for brass students indicating the fact that these musicians are at a higher risk of developing hearing loss. Finally, averaged hearing thresholds per frequency for each instrument group showed a significant threshold notch at 6 kHz, especially in the left ear, indicative of noise-induced hearing loss.

Hearing health surveillance at the Royal Academy of Music will be repeated each year for all new first year students with students to be re-tested at the end of their studies. A statistically significant amount of re-tests, combined with questionnaires assessing the students noise exposure, etc. during their studies, will reveal any rapid changes in the students hearing health that can be associated with music related noise exposure.

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# Hearing loss in professional orchestral musicians

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## INTRODUCTION

According to several studies, professional orchestral musicians are often exposed to sounds at levels exceeding the upper exposure action values from the 2003/10/EC noise directive (Royster et al. 1991; Obeling & Poulsen 1999; Laitinen et al. 2003; O'Brien et al. 2008; Toppila et al. 2011). It has been also shown that players can develop noise-induced hearing loss (NIHL) and suffer from other hearing symptoms such as tinnitus, hyperacusis, ringing in the ears, which can influence their work abilities more severely than hearing loss. However, because of insufficient audiometric evidence of hearing loss caused purely by music exposure, there is still disagreement and speculation about risk of hearing loss from music exposure alone (Axelsson & Lindgren 1981; Karlsson et al. 1983; Royster et al. 1991; Teie 1998; Obeling & Poulsen 1999; Kähäri et al. 2001; Emmerich et al. 2008; Jansen et al. 2009; Zhao et al. 2010).

The aim of this study was to assess hearing status in professional orchestral musicians and its relation with self-reported hearing ability. Another objective was to compare actual audiometric hearing threshold levels with theoretical predictions according to ISO 1999:1990.

## MATERIALS AND METHODS

### Study group

Participants were 85 professional musicians (38 females and 47 males), aged 24−67 years (mean ± SD: 42.9±11.5 years, median: 41.75 years) from two opera and three symphony orchestras. The study group comprised musicians playing violin (21), viola (11), cello (8), trombone (7), oboe (6), flute (6), bassoon (5), horn (4), trumpet (4), double bass (3), clarinet (3), percussion (2), tube (2), guitar (1) and piano (1).

They were recruited by advertisement and did not receive any financial compensation for their participation in the experiment. The local Ethics Committee approved the study design

### Questionnaire inquiries

All musicians were interviewed according to a questionnaire developed to enable identification of occupational and non-occupational risk factors of NIHL. A special attention was paid to professional experience, i.e. the time of employment in orchestra/musical career or comparable experience, various work activities and instruments in use, time of daily and/ or weekly practice, including individual rehearsals.

In addition, musicians' hearing ability was assessed using the (modified) Amsterdam Inventory for Auditory Disability and Handicap ((m)AIADH) (Meijer et al. 2003). This inventory consists of 30 items and includes five basic disability factors dealing with a variety of everyday listening situations: (i) distinction of sounds (subscale I), (ii) auditory localization (subscale II), (iii) intelligibility in noise (subscale III), (iv) intelligibility in quiet (subscale IV), and (v) detection of sounds (subscale V). The respondents were asked to report how often they were able to hear effectively in the mentioned situation. The four answer categories were as follows: almost never, occasionally, frequently, and almost always. Responses to each question were coded on a scale from 0 to 3; the higher the score, the smaller the perceived hearing difficulties. The total score per subject was obtained by adding the scores for 28 questions. Maximum total score of the questionnaire was 84. Additionally, the answers for each subscale were summed up (maximum score for subscale I was 24, while for the other subscale it was 15).

### Hearing examinations

Conventional pure-tone audiometry (PTA) and transient–evoked otoacoustic emission (TEOAE) determinations were made in subjects under study. Before the exact examinations, otoscopy was performed in order to screen for conditions that would exclude examined subject from the study. Hearing tests were performed in quiet rooms located in concert halls and opera building where the background noise did not exceed 35 dBA.

PTA was performed using an Audio Traveller Audiometer type 222 (Interacoustics) with TDH 39 headphones. Hearing threshold levels (HTLs) for air conduction were determined using an ascending–descending technique in 5-dB steps.

A Scout Otoacoustic Emission System ver. 3.45.00 (Bio-logic System Corp.) was applied for recording and analyzing of otoacoustic emissions. TEOAE recordings of 260 averages each were collected for every subject at stimuli levels of about 80 dB, using standard clicks. The artefact rejection level was set at 20 mPa. Each response was windowed from 3.5 to 16.6 ms post stimulus and band-pass filtered from 0 to 6,000 Hz. The total TEOAE amplitude level and the TEOAE amplitude levels for frequency bands with central frequencies 1, 1.5, 2, 3 and 4 kHz were examined.

### Evaluation of exposure to orchestral noise

Musicians' exposures to orchestral noise were evaluated based on data concerning sound pressure levels produced by various group of instruments. These data were collected during measurements performed with the measuring equipments placed in various instrument groups during rehearsals, concerts and performances including diverse repertoire. In general, results of 338 measurement samples (lasting in total approx. 591 hours) were collected (for details see Pawlaczyk-Luszczynska et al. 2011).

For various groups of players the weekly A-weighted noise exposure levels ($L_{EX,w}$) were calculated basing on the median values of equivalent-continuous A-weighted sound pressure levels produced by the respective instrument (e.g. violins or trumpets) and declared time of weekly practice.

### Prediction of noise-induced hearing loss

The musicians' actual hearing threshold levels were compared with the theoretical predictions calculated according to ISO 1990:1990. The aforesaid standard specifies the method for determining a statistical distribution of hearing threshold levels in adult populations after given exposure to noise based on four parameters: age, gender, noise exposure level and duration of noise exposure (in years).

In order to compare predictions obtained for musicians of different gender, age, time and exposure, so-called standardized hearing threshold levels (STHLs) were determined using the following formulas (Sliwińska-Kowalska et al. 2006):

$$SHTL = 1.282 \times (HTL - PHTL_{Q50})/(PHTL_{Q10} - PHTL_{Q50}) \quad \text{for } HTL \geq PHTL_{Q50}$$

$$SHTL = 1.282 \times (HTL - PHTL_{Q50})/(PHTL_{Q90} - PHTL_{Q50}) \quad \text{for } HTL < PHTL_{Q50}$$

Where:
HTL – is the actual hearing threshold, in dB HL,
$PHTL_{Q50}$ – is the median value of predicted HTL in dB HL,
$PHTL_{Q10/\,Q90}$ – is the fractile Q10/ Q90 of predicted hearing threshold level, in dB HL,

These calculations were applied to the audiograms twice, i.e. the musicians' hearing was compared to the hearing of the non-noise-exposed population and noise-exposed population.

## Statistical analysis

A main effects ANOVA was used to analyze the first-order (non-interactive) effects of multiple factors such as: gender, age and exposure on PTA and TEOAE results as well as the (m)AIADH scores. The study group was divided into subgroups according to gender (females and males), age (younger and older subjects) and exposure (lower- and higher-exposed to noise subjects).

Musicians were categorized as higher-exposed or lower-exposed on the basis of assigned theme values of the weekly noise exposure level. Subjects with the $L_{EX,w}$ levels above median value were classified as higher-exposed, while the others as lower-exposed. Similarly, the median value of age was used as the basis for classification subjects as younger and older ones.

The relations between results of PTA or TEOAE and musicians' self-reported hearing ability expressed in terms of the (m)AIADH scores were evaluated using Pearson's correlation coefficient. The standardized hearing threshold levels were analyzed using t-test for dependent samples.

All statistical tests were done with an assumed level of significance $p<0.05$. The STATISTICA (version 9.0) software package was employed for the statistical analysis of the data.

# RESULTS

## Questionnaire inquiries

Musicians under study were employed in orchestras from 1 to 44 years (mean ± SD: 19.5±11.4 years, median: 18.3 years). They were exposed from 7 to 70 hours a week (mean ± SD: 28.8±10.7 h, median: 30 h) to music at the A-weighted equivalent continuous sound pressure levels varying from 73 to 92 dB (Table 1). The weekly noise exposure levels calculated from this data ranged between 81−88 dB (mean ± SD: 84.0±2.0 dB, median: 82.8 dB) (Figure 1).

Generally, almost all subjects (97.7 %) assessed their hearing as good. However, about one quarter of them (23.8 %) noticed hearing impairment, including difficulty in speech intelligibility in noisy environment (40.9 %) and hearing whisper (18.2 %). Nearly every tenth musician complained of tinnitus while one third of them reported hyperacusis.

**Table 1:** Sound pressure levels produced by various groups of instruments (Pawlaczyk-Luszczynska et al. 2011)

| Instrument/ Equivalent continuous A-weighted sound pressure level (10th/ 50th/ 90th percentile) [dB] | | | | | |
|---|---|---|---|---|---|
| Violin | 81/ 84/ 87 | Flute | 83/ 87/ 89 | Horn | 85/ 88/ 92 |
| Viola | 80/ 84/ 88 | Oboe | 83/ 86/ 89 | Trombone | 84/ 87/ 90 |
| Cello | 75/ 82/ 84 | Clarinet | 81/ 87/ 90 | Tuba | 87/ 89/ 91 |
| Double bass | 74/ 83/ 84 | Bassoon | 83/ 86/ 90 | Percussion sect. | 80/ 87/ 91 |
| Harp | 78/ 82/ 85 | Trumpet | 84/ 89/ 91 | Total | 81/ 86/ 90 |

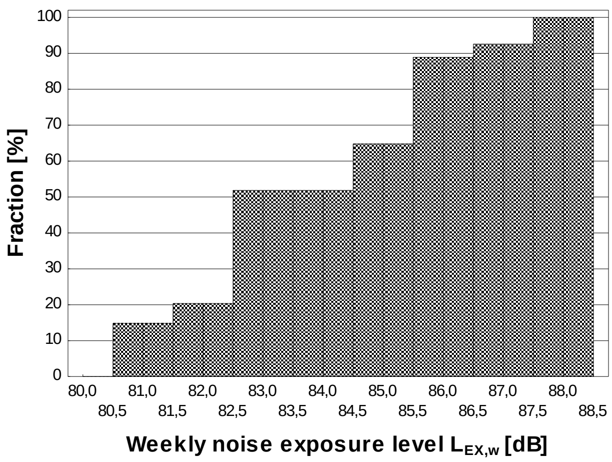


**Figure 1:** Cumulative distribution of the weekly noise exposure level in study group

Musicians examined using the (m)AIADH obtained mean total score of 90.9 % of maximum value, which suggests no substantial hearing difficulties in subjects under study (Table 2). Relatively low scores were frequent only in the subscale evaluating intelligibility in noise (22.2 % of subjects scored below 70 % of maximum value). The (m)AIADH scores were significantly affected by age ($p<0.05$). As expected older subjects obtained lower scores than younger ones. Neither gender nor exposure had impact on the (m)AIAHD scores ($p>0.05$).

**Table 2**: Musicians' self-assessment of hearing ability in the (m)AIADH scores

| Score/ Mean ± SD/ 10th/ 50th/ 90th percentile | | | | | |
|---|---|---|---|---|---|
| Total | Subscale I | Subscale II | Subscale III | Subscale IV | Subscale V |
| 76.4±7.1*<br>65/ 78/ 84 | 23.1±1.4*<br>22/ 24/ 24 | 13.4±1.9*<br>10/ 14/ 15 | 12.4±2.2*<br>10/ 13/ 15 | 13.5±1.9*<br>11/ 14/ 15 | 14.0±1.4*<br>12/ 15/ 15 |

* Significant main effect of age ($p<0.05$)

## Results of PTA and TEOAE

Audiometric hearing threshold levels determined in 85 professional orchestral musicians (165 ears) are shown in Figure 2.

A significant main effect of age on the HTLs was observed in the frequency range from 1,000 to 8,000 Hz (Figure 2b). Generally, older subjects showed higher reduction of hearing threshold level than younger ones. Similar relation was observed between males and females in the in the high frequency region from 3,000 to 8,000 Hz (Figure 2a). There was also a significant main effect of noise exposure on the HTLs at frequencies of 1,000 and 8,000 Hz. Contrary to our expectations higher-exposed subjects ($L_{EX,w}$ >82.8 dB) had lower (better) HTLs compared to lower-exposed individuals ($L_{EX,w}$ ≤82.8 dB) (Figure 2c). However, the latter result is not surprising since the study subjects were generally exposed to sounds at relatively low levels ($L_{EX,w}$≤88 dB).

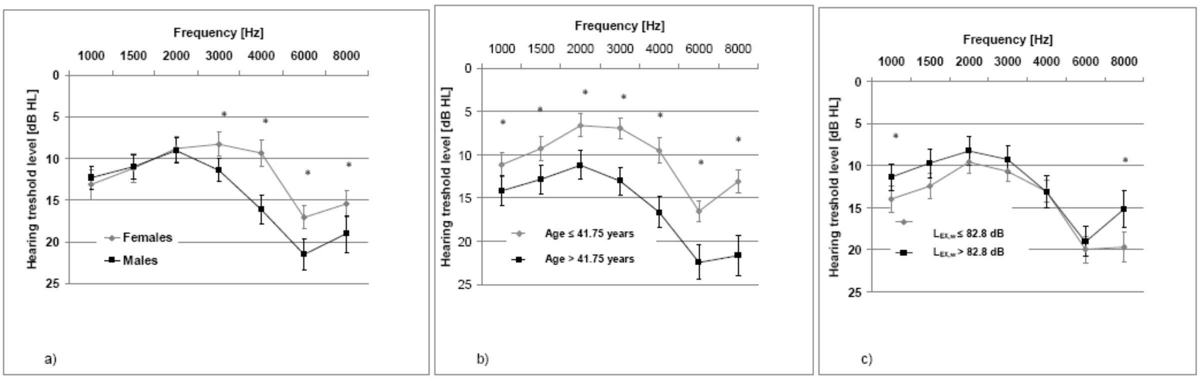


**Figure 2:** Audiometric hearing threshold levels (mean ± 95% CI) in various subgroups of musicians, i.e. females and males (a), younger and older subjects (b), and lower- and higher-exposed subjects (c). Significant differences between subgroups were marked (*)

Typical NIHL notches at 4,000 or 6,000 Hz of at least 15 dB depth relative to the best preceding threshold (from 1,000 Hz) were observed in 36.0 % of audiograms. Most of them (82.8 %) occurring at 6,000 Hz. The portion of total population with bilateral notching at any frequency was 17.1 %.

In the majority (95.2 %) of cases a mean value of the hearing threshold level for 500, 1,000, 2,000 and 4,000 Hz was lower than 25 dB, which corresponds to grade 0 of hearing impairment (WHO 2011). Only 4.8 % of the measured audiograms corresponded to grade 1 of hearing impairment. Moreover, all of them were found in the older musicians.

It is worth noting that according to the classification of the World Health Organization (WHO) in the case of grade 0 ("no impairment") no or very slight hearing problems can occur, and one is able to hear whispers, while in grade 1 ("slight impairment") one is able to hear and repeat words spoken in normal voice at a distance of 1 meter, but hearing aids may be needed (WHO 2011).

Summary results of TEOAE testing are shown in Figure 3. A significant main effect of gender on TEOAE amplitude, signal to noise ratio (SNR) as well reproducibility (excluding frequency band of 1 kHz) was noted (Figures 3a, 3d and 3g). Generally, females showed better results of TEOAE testing compared to males. On the other hand, age and noise exposure were found to significantly affect the reproducibility of TEOAE in the frequency range from 1 to 1.5 kHz (Figures 3e and 3f). As expected, greater reproducibility was observed in case of younger than older musicians while the opposite relation occurred between lower- and higher-exposed to noise subjects

In almost all cases (96.8 % of ears) the reproducibility of the total response of TEOAE was above 60 %. Signal to noise ratio higher than 6 dB was observed in the 69.4 % of cases.

A weak but statistically significant linear relationship was noted between PTA results and the total score of (m)AIADH as well as scores of subscales intended to evaluate intelligibility in noise (subscale III), intelligibility in quiet (subscale IV), and detection of sounds (subscale V) (Pearson's correlation coefficient r varied from -0.45 to -0.25, p<0,05). The linear relationships were also noted between musicians' self-assessment of hearing ability in the (m)AIADH scores and the TEOAE results (0.22≤r≤0.45, p<0.05). The highest values of correlation coefficient were noted between score of subscale III and SNR at 4 kHz as well as HTL at 6,000 Hz.

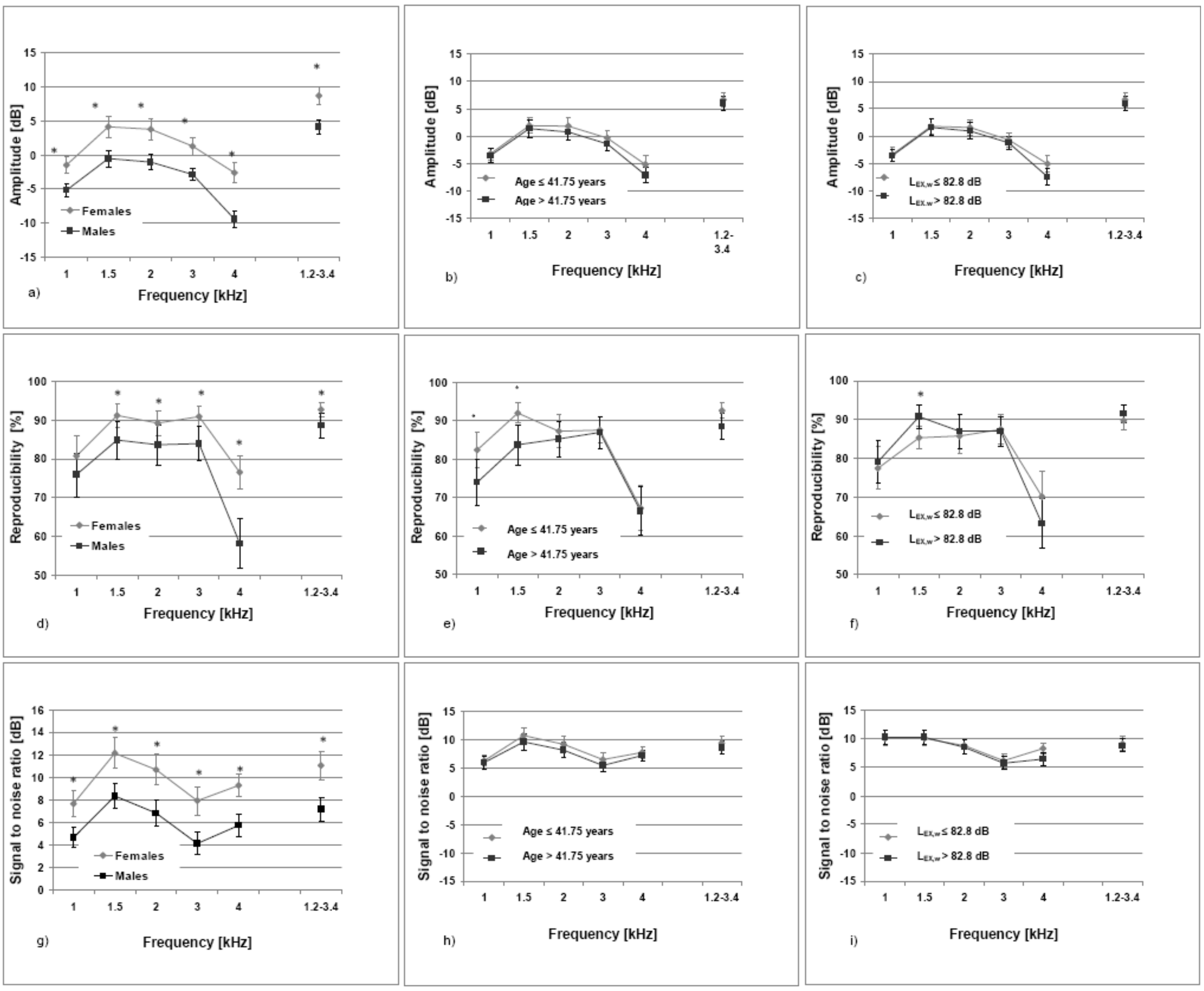


**Figure 3:** TEOAEs (mean ± 95% CI) in various subgroups of musicians, i.e. females and males (a, d, g), younger and older subjects (b, e, h), and lower- and higher-exposed subjects (c, f, i). Significant differences between subgroups were marked (*)

### Comparison of actual and predicted hearing threshold levels

Figure 4 shows standardized hearing threshold levels in musicians under study. It is worth noting that the closer to zero value of SHTL, the better the prediction of hearing loss. On the other hand, the positive values of SHTLs indicate that actual hearing threshold levels are higher than predicted.

Comparing the musicians to non-noise-exposed population revealed that their hearing loss corresponded to the expected hearing loss at frequencies of 3,000 and 4,000 Hz (p>0.05). On the other hand, the actual hearing threshold levels were lower (better) than expected for 3,000; 4,000 and 8,000 Hz (p<0.05), with an expected values at 2,000 and 6,000 Hz (p>0.05), when compared to equivalent population exposed to industrial noise. Thus, findings presented here are in line with some earlier observation that music deteriorates hearing, but less than what ISO 1999:1990 predicted (Obeling & Poulsen 1999; Toppila et al. 2011).

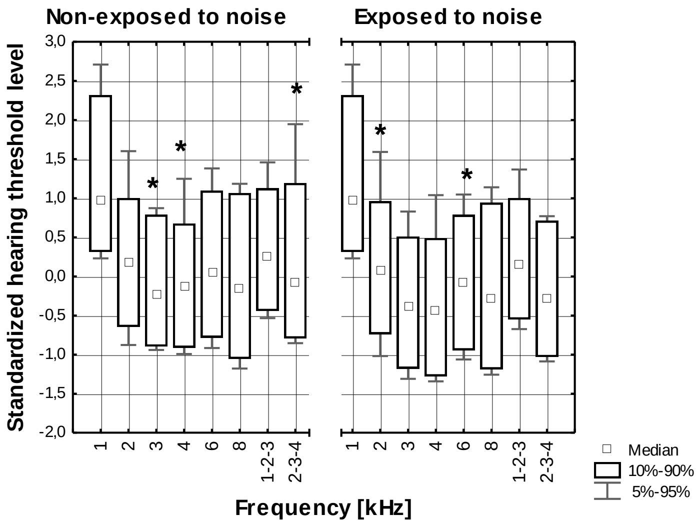


**Figure 4:** Comparison of the musicians' hearing loss to that of non-noise-exposed and noise-exposed populations. Standardized hearing thresholds which do not significantly differ from 0 were denoted (*)

## CONCLUSIONS

- Almost all musicians had hearing threshold levels corresponding to grade 0 ("no impairment") of hearing impairment according to the WHO classification. However, high frequency notched audiograms typical for noise-induced hearing loss were found in 36 % of ears.
- Significant main effects of age and gender on hearing test results were observed. Both PTA and TEOAE showed a tendency toward better hearing in females vs. males, younger vs. older subjects. Moreover, weak but statistically significant linear relationships were noted between musicians' self-assessment of hearing ability in the (m)AIADH scores and the audiometric hearing threshold levels as well as TEOAE results.
- Measured audiometric HTLs at 3,000; 4,000 and 8,000 Hz were lower (better) than theoretical predictions according to ISO 1990:1990. Thus, music deteriorates hearing, but less than expected from exposure to orchestral noise.

## ACKNOWLEDGMENTS

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# The use of hearing protection devices (HPDs) in a group of South African musicians

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## INTRODUCTION

Music induced hearing loss (MIHL) is a form of noise induced hearing loss (NIHL) caused by exposure to music that is at an intensity considered dangerous to the auditory system (Chesky 2008). NIHL, an acquired hearing loss, refers to the damage to or death of the inner hair cells due to exposure to noise. The high frequencies are affected first, regardless of the frequency of the noise source (Schulz 2008). Musicians are at risk for MIHL due to extended periods of noise exposure (Deatherage 2003), which may lead to threshold shifts, tinnitus and reduced dynamic range (Dawson 2007). Threshold shifts caused by noise exposure result in a temporary threshold shift, however, repeated exposure results in a permanent shift were the damage is irreversible (Serra et al. 2007). The effect of MIHL on an individual may include an adverse emotional effect and stress as a result of communication difficulties (Torres 2008). Furthermore, hearing loss may prevent a musician from creating music due to a reduction of the quality of the sound they hear (Noonan 2005). Symptoms of MIHL include reduced hearing acuity, hyperacusis, tinnitus, pain and distortion (Bogoch et al. 2005; Chesky 2008; Chung et al. 2005), all of which may affect a musician's performance.

As a permanent threshold shift is irreversible, prevention of NIHL is critical. Current literature indicates a lack of regulations in the music industry with regard to intensity level limits and hearing conservation programs at entertainment venues to protect musicians from hearing loss (Petrescu 2008). Due to the lack of hearing conservation at live music venues, individuals who are at risk for NIHL should use HPDs during the time of noise exposure (Feuerstein 2002). Three main types of HPDs are available, namely ear muffs, canal caps and ear plugs (Ross 2007). The use of ear muffs and canal caps in the musical industry is not noted in the literature. Ear plugs are the most popular type of HPD used in the music industry and come in three variations; premoulded ear plugs, formable ear plugs and custom ear plugs (Ross 2007). Musicians should preferably make use of custom ear plugs as they reduce distortion and increase attenuation. However, due to availability and funding, many musicians make use of premoulded or formable ear plugs instead (Reid 2005).

It is evident from the paucity of information in the literature reviewed that in South Africa insufficient research has been conducted with regards to NIHL and use of HPDs by musicians. This research aimed to determine if South African musicians are making use of HPDs and the reasoning for their behavior. The sub-aims included to (i) determine to what extent a group of South African Rock and Heavy Metal musicians are currently making use of HPDs, and (ii) determine what affects the musicians' choice to make use of HPDs.

## METHOD

A non-experimental, cross sectional survey design was used for this study. Cross-sectional surveys are used when the data is collected at a particular point in time and when studying attributes of different people (Maxwell & Satake 2006). Surveys are used in research to sample the participant's beliefs and opinions (Maxwell & Satake 2006). Thus a survey was a practical method of obtaining information with regard to musician's beliefs, opinions and practices with regard to NIHL and HPDs.

Twenty four male participants (*n* = 24) were included in this study. All the participants were a member of either a Rock ($n_1$ = 12) or Heavy Metal ($n_2$ = 12) band (See Table 1). They were all exposed to loud music, greater or equal to 85 dBA, on a regular basis, a level that is classified as dangerously loud, thus placing the participants at risk for NIHL (NIOSH 1998).The average age of the participants was 22.4 years (range 19-34 years; standard deviation [SD] - 3.82 years).

**Table 1:** Descriptive information on participants (*n* = 24)

| **Type of band** | **Age in years** | | |
|---|---|---|---|
| | **Mean** | **Range** | **SD** |
| Rock (*n* = 12) | 23.6 | 19-34 | 8.06 |
| Heavy Metal (*n* = 12) | 21.2 | 19-25 | 2.17 |
| TOTAL (*n* = 24) | 22.4 | 19-34 | 3.82 |

A self-developed questionnaire was used to collect the data. The questionnaire had a total of 27 questions categorized into four categories. The categories include demographical information, personal perception of current hearing ability, HPDs, and noise and music as a health hazard. These categories were used to determine what may affect the musicians' choice to make use of HPDs or not.

The data was analyzed using inferential statistics. Inferential statistics are used to determine whether relationships observed in the sample are likely to occur in the larger population (Irwin et al. 2008). Non parametric inferential statistics are used when the data being analyzed refers to the frequency of occurrence, while parametric inferential statistics are used when the data being analyzed are measures such as age (Irwin et al. 2008).

## RESULTS

The results were analyzed to determine the use of HPDs by the group of South African musicians and to determine what affects the musicians' choice to make use of HPDs according to the categories presented in Table 2.

Following data-analysis, participants were divided into two groups (G1 & G2) to compare the results of the musicians who make use of HPDs (G1) to those who do not (G2).

**Table 2:** Categories of the questionnaire correlating to the results sub-categories

| **Questionnaire Categories** | **Sub-Categories** |
|---|---|
| Demographical information | Age<br>Number of years playing an instrument<br>Hours exposed to noise per week<br>Genre<br>Instrument |
| Personal perception of current hearing ability | Self-rating of hearing<br>Experience of ear fullness<br>Experience of tinnitus |
| HPDs | Knowledge of HPDs and their availability to musicians<br>Cosmetic Aspects of using HPDs<br>Effects of HPDs on the clarity of the music |
| Noise and music as a health hazard | Belief that noise can damage the auditory system<br>Belief that music is noise<br>Belief that music may damage the auditory system |

### Age

The average age of the participants in G1 was 23.06 years (range 20 – 34 years; SD - 4.53 years). In G2 the average age was 21.22 years (range 19 – 24 years, SD - 2.28 years). The results indicate that the majority of participants make use of HPDs as G1 consisted of 15 participants (63 %) and G2 consisted of 9 participants (27 %) (see Table 3).

**Table 3:** Participant demographical information

| | Group 1: Use HPDs ($n$ = 15) | | | Group 2: Non-use of HPDs ($n$ = 9) | | |
|---|---|---|---|---|---|---|
| | Mean | Range | SD | Mean | Range | SD |
| Age (in years) | 23.1 | 20 – 34 | 4.53 | 21.2 | 19 - 24 | 2.28 |
| Musical instrument experience (in years) | 7.7 | 1 - 20 | 5.41 | 8.4 | 3 - 19 | 5.29 |
| Noise exposure per week (in hours) | 23.3 | 6.7 – 56.8 | 18.06 | 19.9 | 4.3 – 84.3 | 24.93 |

The two sample t-test was used to analyze the data, $t$ = 1.3621, $p$<0.05 and $df$ = 22, thus the critical value is 2.0739. As the $t$ value was less than the critical value, it is indicated that the use of HPDs is not influenced by the age of the participant.

### Musical experience and exposure to noise

The *musical experience* in G1 was on average 7.7 years (range 1 – 20 years, SD - 5.41) and in G2 8.4 years (range 3 – 19 years, SD - 5.29) (see Table 3). The two sample t-test was used to analyze the data, $t$ = 0.31117, p<0.05 and $df$= 22, thus the critical value is 2.0739. As the $t$ value was less than the critical value, the use of HPDs is not influenced by the number of years the musicians have played for.

The *hours exposed to noise per week* for each participant was calculated by adding the hours they practiced each week, hours they played live each week and other hours per week where they were exposed to noise such as watching other live bands or teaching music. G1 averaged at 23.3 (range 6.7 – 56.8; SD - 18.06) while G2 averaged at 19.9 hours of exposure per week (range 4.3 – 84.3; SD - 24.93). The Mann-Whitney test was used to analyze the result $U= 77.5$, $p<0.05$, with $n2=15$ and $n1=9$ thus the critical value was 34. As the U value is required to be less than or equal to the critical value the results indicated that the use of HPDs is not influenced by hours of noise exposure per week experienced by the musicians.

It was also found that only 60 % of participants in G1 made use of the HPDs during all noise exposure periods. Seven percent of the participants in G1 only made use of HPDs during practice sessions and not during gigs, while the remaining 33 % reported that they sometimes use HPDs but did not specify when. This indicates that although a majority of the participants are making use of HPDs, they are not all using the HPDs during all exposures to noise.

**Use of HPDs by genre and instrument type**

Of the 15 participants in G1, eight were Metal musicians and nine were Rock musicians. In G2 four participants were Metal musicians and five were Rock musicians. Chi square was used to analyze the results. $\chi^2 = 0.17777$, $p<0.05$ and $df = 1$ thus the critical value was 3.841 indicating that the use of HPDs is not influenced by the genre. The participants in this study played a variety of *instruments*. These instruments included six vocalists, nine guitarists, six bassists and five drummers. In G1 there were two vocalists, eight guitarists, four bassists and two drummers while G2 consisted of four vocalists, one guitarist, two bassists and three drummers. One participant from each group played two instruments. Chi square was used to analyze the results. $\chi^2 = 5.194593$, $p<0.05$ and $df = 3$ thus the critical value was 7.815 indicating that the use of HPDs is not influenced by the instrument played.

**Personal perception of current hearing ability**

The participants were asked to rate their own hearing, as well as their experience of aural fullness and tinnitus after noise exposure. When asked to rate their *current hearing ability*, of the participants in G1, four stated their hearing was perfect, six felt their hearing was normal, five believed it was slightly worse than when they were younger and none believed it was noticeable worse than when they were younger or had a known hearing loss. In G2, four believed their hearing was perfect, four thought it was normal and one believed their hearing to be noticeably worse than when younger. Chi square was used to analyze the results. $\chi^2 = 5.226667$, $p<0.05$ and $df = 4$ thus the critical value was 9.488. Thus the results indicated that the use of HPDs is not influenced by the musicians' perception of their hearing abilities.

The participants were asked to rate their experience of *aural fullness* after exposure to noise. Of the participants in G1, four stated they never experienced aural fullness, none stated they experienced aural fullness after practice sessions, seven stated they experienced aural fullness after gigs and three stated they experience aural fullness after practice and gigs. Of the participants in G2, one stated they never experienced aural fullness, one stated they experienced aural fullness after practice sessions, one stated they experienced aural fullness after gigs and three stated they experience aural fullness after practice and gigs. Chi square was used to analyze the results. $\chi^2 = 8.259378974$, $p<0.05$ and $df=4$ thus the critical value was 9.488. Thus the results indicated that the use of HPDs is not influenced by the musicians' experience of aural fullness after noise exposure. Seventy eight percent of the participants experienced ear fullness after noise exposure.

The participants were asked to rate their experience of *tinnitus* after exposure to noise. Of the participants in G1, five stated they never experienced tinnitus, two stated they experienced tinnitus after practice sessions; six stated they experienced tinnitus after gigs and two stated they experience ear fullness after practice and gigs. Of the participants in G2, three stated they never experienced tinnitus, none stated they experienced tinnitus after practice sessions; one stated they experienced tinnitus after gigs and three stated they experience tinnitus after practice and gigs. Chi square was used to analyze the results. $\chi^2$ =7.147857143, p<0.05 and *df*=4 thus the critical value was 9.488. Thus the results indicated that the use of HPDs is not influenced by the musicians' experience of tinnitus after noise exposure.

**HPDs**

The participants' *knowledge of HPDs* was determined as they were asked what types of HPDs are available and where they may be purchased from. All of the participants in G1 and G2 knew what HPDs were and could give examples of different types of HPDs. All the participants in G1 and six of the participants in G2 knew where to purchase HPDs. Chi square was used to analyze the results. $\chi^2$ =10.04464286, p<0.05 and *df*=1 thus the critical value was 3.841. Thus the results indicated that the use of HPDs is influenced by the musicians' knowledge of where HPDs may be purchased from. The comparison of the two groups, those who make use of HPDs and those who do not indicated that the main contributing factor to the use of HPDs is knowledge of HPDs specifically where they may be purchased. All of the musicians in G1 were able to list places such as audiologists, pharmacies and hardware stores, where HPDs may be obtained.

The participants were asked if the *cosmetic aspects of HPDs* would affect them from using them. In G1 two participants stated they would be affected and 13 stated they would not be affected. In G2 three participants stated they would be affected and six stated they would not be affected. Chi square was used to analyse the results. $\chi^2$ =1.364210526, p<0.05 and *df*=1 thus the critical value was 3.841. Thus the results indicated that the use of HPDs is not influenced by the cosmetic aspects of HPDs.

The participants were asked to describe the *effects of HPDs* on the quality of the music. In G1, one participant stated that the HPDs had no effect on the quality of the music, nine stated they improved the quality, six stated they distort the signal and one stated he did not know. In G2, none participants stated that the HPDs had no effect on the quality of the music, three stated they improved the quality; four stated they distort the signal and two stated they did not know. Chi square was used to analyze the results. $\chi^2$ =2.509368194, p<0.05 and *df* = 3 thus the critical value was 7.815. Thus the results indicated that the use of HPDs is not influenced by the musicians' perception of the effects of HPDs on the quality of the music. It should be noted that although 53% of the musicians in G1 felt that HPDs improve the quality of the music compared to the 33% of those in G2. However, this difference is not significant.

**Noise and music as a health hazard**

The participants were asked if they believed that exposure to loud noise may damage the auditory system. All of the participants in G1 and G2 believed that noise is harmful to the auditory system. Thus, indicating that the knowledge of the effects of noise on the auditory system does not influence the use of HPDs. This indicates that as all the participants are aware that noise may damage the auditory system, education programs should focus on the long-term effects of such as the effects of hearing loss on daily living.

The participants were then asked if they believed that music may be considered as noise. In G1, ten participants believed that music is a form of noise while five believed that it is not. In G2, seven participants believed that music is a form of noise while two believed that it is not. Chi square was used to analyze the results. $\chi^2$ =0.336134453, p<0.05 and *df*=1 thus the critical value was 3.841. Thus the results indicated that the use of HPDs is not influenced by the musicians' belief that music may be considered noise.

The participants were asked if they believed that exposure to music may damage the auditory system. In G1, 14 participants believed that music exposure may damage the auditory system and one believed that it could not. In G2, eight participants believed that music exposure may damage the auditory system and one believed that it could not. Chi square was used to analyze the results. $\chi^2$ =0.145454545, p<0.05 and *df*=1 thus the critical value was 3.841. Thus the results indicated that the use of HPDs is not influenced by the musicians' belief that music may damage the auditory system. These results indicate that the majority of the participants are aware that music may damage the auditory system and thus they are at risk of NIHL.

DISCUSSION

**Demographical information**

This study indicated that the demographical attributes of the musicians (age, number of years of musical experience, genre of music, instrument played and weekly hours of noise exposure) did not affect their use of HPDs. As the majority of participants' in this study are under 25 years of age, this may explain why age is not a contributing factor to the use of HPDs, as compared to previous studies which indicate that age does affect HPD use (Goodman 2001; Laitinen 2005). The results indicating that HPD use is not affected by years of musical experience, was not unexpected as previous research on this topic has had conflicting results, Goodman (2001), found that individuals' who had more musical experience were less likely to make use of HPDs as they experience more distortion as a result of hearing loss. While Laitinen (2005), found that musicians are more likely to make use of HPDs after they have developed a hearing loss. This study found that although a majority of the participants are making use of HPDs, they are not all using the HPDs during all exposures to noise. These results correlate to a study conducted by Laitinen & Poulsen (2008) who found that the musicians who do make use of HPDs generally use them inconsistently and not during all times of noise exposure.

**Personal perception of current hearing ability**

The study indicated that the musicians' perception of hearing ability (self-rating of hearing, experiencing aural fullness and experiencing tinnitus after music exposure) did not affect their use of HPDs. As discussed above, hearing loss has conflicting results on the use of HPDs (Goodman 2001; Laitinen 2005), which may have counterbalanced each other out in this study. Twenty five percent of all participants feel that they have some degree of hearing loss, 78 % experience aural fullness and 79 % experience tinnitus after noise exposure; however none of the participants have been to an audiologist for a hearing assessment. This may reflect the musicians' knowledge regarding the role of audiologists in hearing assessment and management.

### HPDs

This study indicated that the cosmetic aspects of HPDs and the effects of HPDs on the perceived quality of the music did not affect the musicians' use of HPDs. However, the comparison of the two groups, those who make use of HPDs and those who do not indicated that the main contributing factor to the use of HPDs is the knowledge of HPDs specifically where they may be purchased. All of the musicians in G1 were able to list places where HPDs may be obtained whereas 40% of the participants in G2 did not know where HPDs could be purchased. These results correlate with previous research that indicates increased awareness of HPDs increases the use of HPDs (Wilton 1999). This is an important consideration for awareness programs in the music industry. Furthermore, musicians require an adjustment period to be accustomed to the HPDs before they experience the benefits of HPDs (Laitinen & Poulsen, 2008). Thus awareness programs in the music industry should highlight that an adjustment period is required and that once musicians have become accustomed to the HPDs they perceive the HPDs as beneficial and feel that the HPDs improve the quality of the music.

### Noise and music as a health hazard

This study indicated that the knowledge of the effects of noise on the auditory system, the musicians' belief that music may be considered noise and the musicians' belief that music may damage the auditory system did not affect their use of HPDs. This does not correlate to previous studies that have indicated that musicians' are unwilling to make use of HPDs as they do not consider music noise and aim to produce the high intensity sounds (Everton 2004). As all the participants were aware that noise may damage the auditory system, education programs should focus on the long-term effects of such as the effects of hearing loss on daily living.

## CONCLUSION

The use of HPDs is affected by the musicians' knowledge of HPDs; however, no other single factor contributes to the musicians' choice to make use of HPDs. It is thus evident that musicians require general education regarding the importance of hearing conservation. The audiological community should become involved in education programs in the music industry regarding the effects of hearing loss, the signs and symptoms of NIHL and the steps that should be followed for assessment and treatment of hearing loss. This is imperative for the prevention and early identification of hearing loss which will lessen the burden on the health care system (Ross 2007). It is also proposed that a change of legislation is required in South Africa to include the music industry in future Occupational Health and Safety Acts.

Recommendations for future research include that this study be replicated on a larger sample size as this may provide more information regarding the factors that affect the use of HPDs in South African musicians. It is also recommended that the research be replicated with musicians from different genres to compare the use and awareness of HPDs across the different music genres. A further study should be performed to determine the effectiveness of educational programs in the music industry. Finally a study comparing the use of HPDs in musicians who received formal music training and those who have not to determine if music colleges in South Africa are promoting hearing conservation.

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# Assessment of life course noise exposure

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## INTRODUCTION

Any sound will cause hearing loss as long as it is loud enough and of sufficient duration. NIHL in the workplace, however, mainly arises from continual exposure to loud sound (noise) above a level of around 80-85 dBA and is recognized as an occupational disorder in many work settings (Dobie 2001). Acute exposure to very loud sound can also lead to rapid damage to the ear and loss of hearing. Loud sound is also a hazard in non-work related environments but the distinction between the two contexts is increasingly recognized as artificial and unhelpful (Smith et al. 2006). The hearing loss occurs because of damage to the hearing organ (cochlea) of the inner ear; mainly the auditory sensory hair cells and their associated nerves (Thorne & Gavin 1987; Wang et al. 2002).

The severity of the hearing loss and rate at which it develops is defined primarily by the level and duration of the exposure. The New Zealand national standard for occupational exposure to noise is an eight-hour equivalent continuous A-weighted sound pressure level of 85 dB $L_{Aeq}$,8h, while the maximum peak level permitted is 140 dB LC,peak. This is set in law by Health and Safety in Employment Regulations (1995). With repeated exposure at this level over a working week, only 5 % of the exposed population should have a hearing loss greater than 10 dB over a working lifetime (Standards Australia/Standards NZ 2005). The risk and severity of hearing loss rises with duration and sound level (Dobie 1995, 2001).

Epidemiological data on NIHL has been collected using various methods including quantitative hearing assessment, self-reports (e.g. European Agency on Safety and Health at Work 2005), questionnaires (e.g. Palmer et al. 2000, 2001) and the number of people receiving compensation for NIHL (Thorne et al. 2006). Estimates of the incidence and prevalence of NIHL in different countries vary considerably. This variation is due to differences between the populations and their noise exposure, and includes: variations in the audiometric criteria for defining degree of hearing loss; differences in hearing conservation programs and use of personal hearing protectors; and in criteria for attributing the proportion of hearing loss due to noise exposure rather than age or other disease. Based on the WHO definition for substantial or significant hearing loss (> ave 41 dB loss for 0.5, 1, 2 and 4 kHz), an estimated one sixth (16 %) of the population with hearing loss worldwide is attributable to occupational noise exposure (WHO 2002). This figure is corroborated by a USA assessment of the contribution of occupational noise exposure to total deafness rates, giving a range from 7 % in developed nations to 21 % in developing regions (Nelson et al. 2005). Part of the difficulty in estimating the rate of NIHL may result from the quality of information about the extent of noise exposure in the nominally noise-exposed populations.

Long-term memory about health factors is generally poor and epidemiological research has sought to use mnemonic tools to improve recall accuracy. We sought to assess life-course noise exposure in a sample of adults using a mnemonic approach:

the Noise-History Calendar. This is based on the Life-History Calendar, which is a well-established instrument used to enhance the quality of retrospective data (Caspi et al. 1996). The technique has not, to our knowledge, been used previously to help identify and quantify historical noise exposure. It takes the form of a series of columns, each representing a year, and extends back in time as long as is necessary to describe the noise exposure of an interviewee. Other events that have occurred in a person's life (e.g. changing jobs, moving house etc.) can be indicated on the Calendar and serve as points of reference to improve the quality of recall.

For noise exposure, both the level of noise and the amount of time exposed is important to understanding an individual's degree of noise exposure. Previous epidemiological research has used the question: "Is the noise at work so loud that you need to shout to converse when you are at arm's length from someone?" This question has been used widely (e.g. McBride 1993) but with little supporting research. The amount of time exposed can be related to the proportion of an eight-hour work shift on the basis of the equal energy hypothesis. Finally, noise exposure should also take into account the use of hearing protection equipment that would have the effect of reducing the noise level at the ear.

It would be useful to have a standard technique for the assessment of lifetime noise exposure. We began work on establishing such a technique.

## METHODS

We interviewed 500 people working in a range of economic sectors in New Zealand. Sampling was purposive, to enlist a predominance of workers from the noisy occupations (such as metal manufacturing), but others, currently working in quiet occupations, were also recruited. Participants were mostly (75 %) male, and of NZ European ethnicity (59 %); their mean age was 39 years (SD=12.8; Age range: 17-75 years).

Participants were interviewed at work using the Noise-History Calendar (Figure 1). Their life-course noise histories were explored starting in the current year and progressing backwards through time; to assist with recall, interviewers were instructed to elicit information about different jobs, places of residence, and other life events that the participant could bring to bear on assisting with recall about their working conditions. They were asked to indicate for each occupation and each year what the average percentage of time they were exposed to noise at a level where they had to shout to converse with someone else when they were at arm's length. They were also asked about the proportion of time that it was noisy at this level when they would have worn hearing protection. On the following day, prior to starting work, otoscopy, tympanometry, and pure-tone audiometry (at 1, 2, 3, 4, 6, and 8 kHz) were carried out on each participant. For 443 of the participants, a dosimeter was then attached to them for the full work shift and collected that evening after work.

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|---|---|
| Job | | | | | | | | | | |
| Noisy? (Including sudden, loud noises) | | | | | | | | | | |
| Protection? | | | | | | | | | | |

**Figure 1:** Scaled-down version of a page from the Noise-History Calendar

Several measures of noise exposure were derived:

Years of noise exposure (YNE): This was a simple count of the number of years that each person indicated they had worked in noisy conditions where they had to shout to converse when at arm's length.

Weighted YNE (WYNE): This was the number of years that each person reported being noise exposed multiplied by the proportion of time exposed for each year.

Corrected WYNE (CWYNE): The question asked to standardize reporting levels for noise was whether they had to shout to hold a conversation when at arm's length from other workers. It was not known what level this might have reflected, so a comparison was made between the noise level that each person estimated for his current occupation and the noise level as measured by dosimetry. This yielded a correction factor for each person, depending upon how closely their interpretation of the level of noise exposure at which they would have to shout to hold a conversation was to 85 dBA. This level was used because it represents the legal limit for noise exposure over an eight-hour shift in New Zealand.

## RESULTS

Overall, most of those interviewed worked in some noise. The proportion of the group exposed to noise at work had been quite constant over the years (Figure 2).

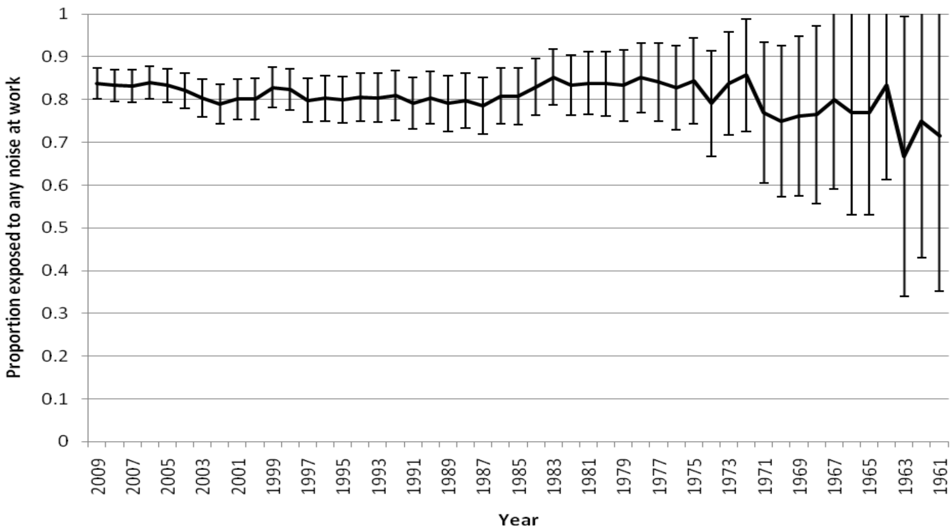


**Figure 2:** Proportion of those interviewed who were exposed to noise in each calendar year. (Error bars represent 95% CI)

The percentage of time during a work shift that participants estimated they were exposed to noise did not alter across time (Figure 3).

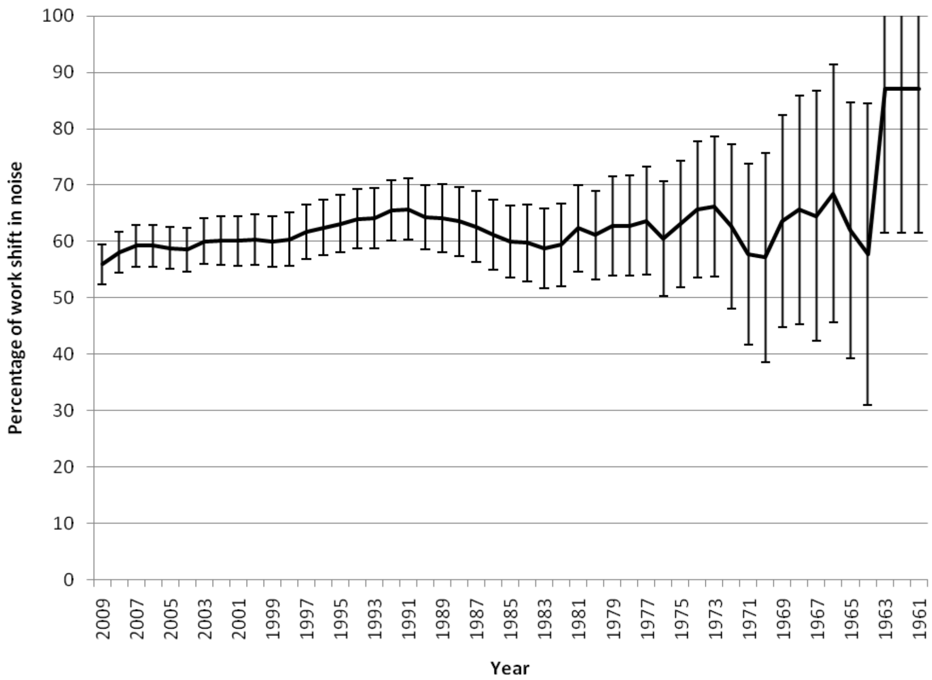


**Figure 3:** Percentage of time during a work shift that noise was loud enough that it was necessary to shout to converse when at arm's length. Percentages are presented per year, and error bars represent 95% CIs

However, the wearing of hearing protection equipment during noise has increased (Figure 4).

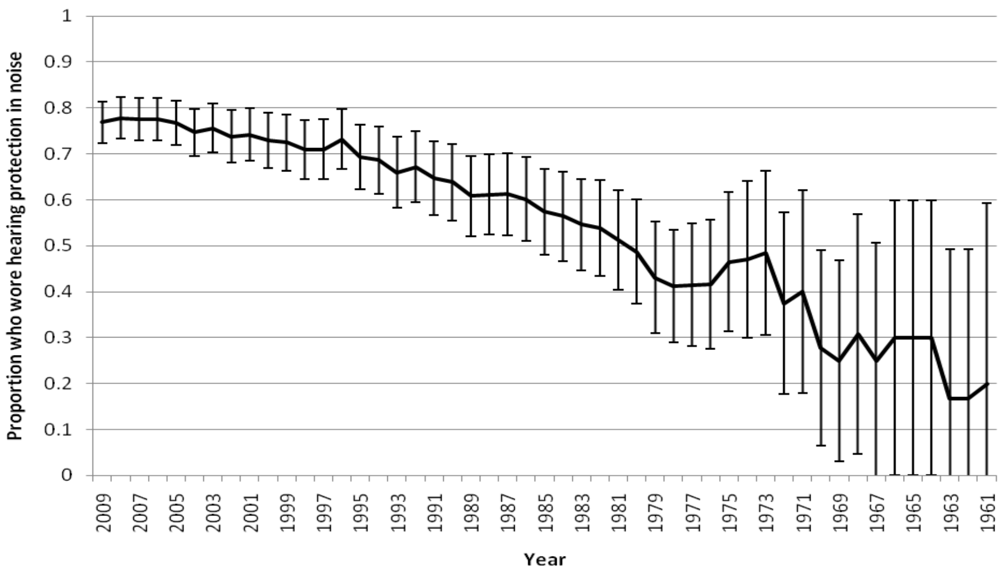


**Figure 4:** Proportion of people who wore hearing protection equipment when working in noise per year. (Error bars represent 95% CI)

**Table 1:** Number and percentage who over or underestimated percentage of time during a work shift that they were exposed to noise aranged by noise levels

| | 75 dB | 80 dB | 85 dB | 90 dB |
|---|---|---|---|---|
| N employees who **overestimate %NE** | 181 | 249 | 288 | 299 |
| % | 40.9 % | 56.2 % | 65.0 | 67.5 |
| N employees who **underestimate %NE** | 257 | 168 | 89 | 41 |
| % | 58.0 % | 37.9 % | 20.1 | 9.3 |
| N employees with **EQUAL estimate of %NE** | 5 | 26 | 66 | 103 |
| % | 1.1 % | 5.9 % | 14.9 | 23.3 |

The percentage of noise exposure as measured by minutes of dosimetry above each of the levels (70, 75, 80, 85, and 90 dBA) as a percentage of the total minutes in the shift was compared to each participant's estimate of their noise exposure at a level where they would have to shout to be heard (Table 1). In general, the noise level at which estimates would be evenly split between too high and too low would be at a level between 75 and 80 dBA. This may suggest that our criterion question for noise exposure (shouting to converse at arm's length) was, on average, interpreted by participants as a noise level of about 78 dBA.

Based on this, and given that 85 dB $L_{Aeq,8h}$ is the level regarded by New Zealand law as the criterion for dangerous exposure it was desirable to attempt to correct the discrepancy between the interpretation of our question and the legal criterion. To do this, comparisons were made between dosimetry results and the percentage estimates that participants made for their current jobs. Ratings were then were made for each participant of the noise dose (relative to 85 dB $L_{Aeq,8h}$) asociated with their rating of the percentage time exposed. For example, if a participant rated current noise exposure at 100 % and dosimetry showed an actual noise dose of 82 dB $L_{Aeq,8h}$, then this level would be applied to all his estimates of past noise exposure.

Based on this approach, a pattern of noise exposure (relative to the legal criterion) across time was developed (Figure 5). Error bars are wide, but this may suggest that the rate of noise exposure has grown since the 1960s. The result may be an artefact due to older workers being more likely to overestimate current noise levels and thus implying that their noise exposures 40-50 years ago were lower than they really were.

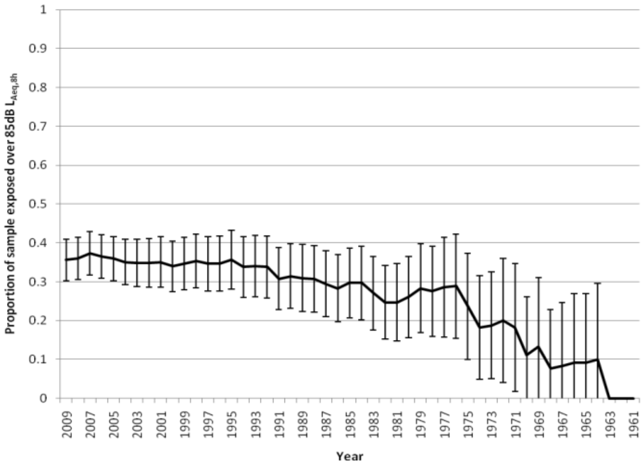


**Figure 5:** Proportion of the participants who were working in each year whose rated noise exposure percentage translated to a shift exposure >85 dB $L_{Aeq,8h}$. Error bars represent 95% CIs

## CONCLUSIONS

The Noise–History Calendar appears to be effective technique for estimating exposure to noise.

It uses a paper calendar as a mnemonic to support recall of noise levels and times of exposure.

Accompanying this are standardized questions to assess the length and level of noise exposure.

Responses to the question, 'Did you have to shout to converse when at arm's length?' tended to reflect actual noise levels between 75 and 80 dBA

Noise exposure rates in New Zealand appear to have been constant or possibly slightly increasing over the last 50 years.

Use of Hearing Protection Equipment when working in noise has increased gradually in the last 50 years and appears to have leveled off at between 70 % and 80 % of workers wearing it over the last two decades.

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# The monitoring role of otoacoustic emissions and oxidative stress markers in the protective effects of antioxidant administration in noise-exposed subjects: a pilot study

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## INTRODUCTION

Noise-induced hearing loss (NIHL) is a major cause of hearing disability, accounting for about 16 % of all disabling hearing losses in the adult population worldwide (Nelson et al. 2005). Prevention of NIHL is based on several hearing-preservation methods, such as reduction of noise sources, the use of hearing-protection devices, the development of hearing-loss screening, and basic education for the high-risk population. In recent years, significant contributions to identify the underlying pathways of damage have been posted, with new perspectives for clinical prevention and treatment. Death of hair cells after acoustic trauma may be due to direct mechanical trauma and/or a result of increased metabolic activity in the inner ear (Le Prell et al. 2007). Several studies have shown that the generation of reactive oxygen species (ROS) and free radicals is involved in the cascade of cochlear events that induces acoustic trauma (Henderson et al. 2006). Depending on the severity, frequency, duration, and temporal characteristics of noise (impulse noise versus continuous noise), the effects on the cochlea range from a moderate disappearance of the hair cell stereocilia and moderate damage of the stria vascularis and lateral wall to a complete fracture of the organ of Corti and rupture of the Reissner’s membrane (Hamernik et al. 1984). Evoked otoacoustic emissions (EOAEs) represent an accurate, objective, fast, and noninvasive tool for assessing outer hair cells (OHCs) function in experimental and clinical studies (Probst et al. 1991).

In a recent paper, DPOAEs (distortion product otoacoustic emissions) measured with a standard technique in a group of young workers exposed to brief occupational noise had good sensitivity and specificity for higher frequencies (Sisto et al. 2007). Different approaches to reduce or prevent the effects of noise have been employed in experimental models, ranging from restoration of the ROS balance using antioxidants or substrates for antioxidant synthesis and limitation of the amount of lipid peroxidation that occurs in the organ of Corti after noise trauma to inhibition of selected pathways that result in apoptotic cell death of the OHCs (Henderson et al. 2006).

It has been also demonstrated that ROS trigger oxidative stress and the activation of mitogen-activated protein kinase (MAPK). This, in turn, increases c-Jun N-terminal kinase (JNK) signal transduction, involved in the production of pro-inflammatory cytokines which enhance tumor necrosis factor (TNFa) expression in the OHCs and finally trigger apoptosis (So et al. 2007; Wang et al. 2007). Signs of inflammation leading to necrosis have been demonstrated in the cochlea a few minutes after noise exposure (Hu et al. 2006). Increasing antioxidant levels in the organ of Corti following oxidative stress induced by higher mitochondrial activity, glutamate excitotoxicity, and ischemia/reperfusion insult represents a rational approach against NIHL (Henderson et al. 2006); many antioxidant agents have been tested successfully.

The aims of this study are: 1) to evaluate whether DPOAEs can discriminate among normal hearing subjects (young age, no systemic and/or ear pathologies, no occupational noise exposure) those with early cochlear damage due to loud sound exposure, 2) to assess the effectiveness of EOAEs in monitoring the protective effects of Coenzyme Q-Ter. (CoQ-Ter.), an antioxidant drug that was shown to prevent NIHL and OHC mitochondrial dysfunction in a previous experimental study (Fetoni et al. 2009), and 3) to evaluate whether systemic inflammatory and antioxidant parameters could be an adjunctive and effective method of monitoring the effects of drug administration to prevent NHIL in clinical practice.

METHODS

## Subjects

Twenty young volunteer male students (40 ears) between 23 and 28 years old (mean: 26.4 years) were enrolled in this study. None of the subjects had a history of treatment with ototoxic drugs, shooting experiences, systemic disease such as diabetes, or any past or present middle ear infection. All subjects had a negative history for occupational or hobby noise exposure and were fully informed of the aim, design, and clinical applications of this study.

A general otolaryngological examination and standard tympanometry were performed in every subject to exclude middle ear pathologies. Conventional pure-tone audiometry was carried out in a soundproof room and the pure-tone thresholds of each ear were measured at frequencies of 0.125, 0.25, 0.50, 1, 2, 3, 4, 6, and 8 kHz with an Interacoustics audiometer. Subjects with pure-tone thresholds greater than 20 dB at any of the tested frequencies were excluded from the study. DPOAE measurements DPOAEs were recorded in a sound-attenuated chamber by an ILO-92 instrument (Otodynamics) as previously shown in Di Girolamo et al. (Di Girolamo et al. 2001). The acoustic stimuli were two 70-dB SPL equilevel (L1-L2) primary signals (f1 and f2) simultaneously delivered through a catheter inserted into the external auditory canal, with an automatically determined f2:f1 ratio of 1.22. Nine pairs of stimuli were used corresponding to f2 frequencies of 1001, 1257, 1587, 2002, 2515, 3174, 4004, 5042, and 6348 Hz. For each pair of stimuli the DPOAE level was measured (as sinusoidal acoustic emission) and the frequency was calculated using the equation 2f1–f2. Data were evaluated by assuming that f2 corresponded to the specific cochlear region considered mainly responsible for the distortion products. DPOAEs were measured and recorded as the average of four separate spectral averages of each stimulus condition. The noise level was measured at a frequency of 50 Hz above the DPOAE frequency using similar averaging techniques. For graphic analysis, a plot of mean DPOAE levels was constructed as a function of the stimuli (DP-gram).

## Blood tests

Blood samples were collected via venipuncture of the antecubital vein before and 2 and 24 h after Q-Ter. or placebo administration and noise exposure. For nitrite determination, the blood samples were processed using specific methodologies to limit artifactual **ex vivo** hemolysis and levels of plasma hemoglobin. Total antioxidant capacity (TEAC) was determined in the serum samples using a method developed by Rice-Evans and Miller (Rice-Evans & Miller 1994).

### Drug preparation

Q-Ter. is a terclatrate substance obtained by mechano-physical activation, a solid-state procedure that brings different substances into supramolecular contact through the administration of energy and turning a simple mixture into a multicomposite material (applicant: Patent WO/2003/097012, Actimex Srl, Italy). Q-Ter. consists of an outer case (an inactive pharmaceutical grade excipient) entrapping CoQ10 moieties (10 % w/w) and an amino acid that serves as a catalyst to enable the formation of the multi-composite. Q-Ter. was provided by Pharmaland (Repubblica di San Marino, Italy) and was manufactured using an industrially available native CoQ10 (Kaneka Pharma Europe, Brussels, Belgium). Q-Ter. was prepared in 200-mg tablets. The placebo tablets contained 196 mg of microcrystalline cellulose and 4 mg of magnesium stearate.

### Experimental design

This preliminary study was designed in a prospective, randomized, double-blinded manner. Twenty volunteers were enrolled and randomized to two groups. The subjects of the first group (n=10, 20 ears) were treated with Q-Ter. At a dose of 200 mg given orally once a day for 7 days before noise exposure. The subjects of the second group were treated with the same dose of placebo at the same time points. Noise exposure was performed in the ENT Division of Turin University. Briefly, acoustic trauma was induced by continuous white noise (WN) at a 90-dB HL intensity for 15 minutes generated by a commercial Interacoustics audiometer. The sound was symmetrically presented in open field in a soundproof room. In all subjects, blood was drawn before and 2 and 24 h after noise exposure and drug administration. Audiological evaluation with DPOAEs was performed before and 1 h, 16 h, and 7 and 21 days after sound exposure. Testing was repeated 1 min after the first recording to evaluate intra-individual variability. Pure-tone audiometry was carried out before and at each time point, but only those performed at 1 h and 7 days were considered for statistical analysis.

### Statistical analysis

The statistical significance of DPOAE amplitude and pure tone audiometry (PTA) data was calculated by analysis of variance (treatment Å~ time points Å~ side, three-way ANOVA with repeated measures). A two-way ANOVA with repeated measures was used for statistical analysis of blood antioxidant and inflammatory markers. When significant differences were found with the overall analysis, post hoc comparisons were assessed with Tukey’s test (Sigmastat, USA). A **p** value of <0.05 was considered significant.

## RESULTS

### Audiological evaluation

Before treatment and noise exposure, the DPOAE amplitudes in the subjects treated with Q-Ter. and placebo did not differ (**F**=1.420, **p**=0.234). No DPOAE amplitude modifications were observed within the test. Comparison between the Q-Ter. and placebo groups at different time points (treatment Å~ time points) revealed statistical significance (**F**=17.435, **p**<0.001); however, no significant differences were observed comparing right and left ears (treatment Å~ time points Å~ side, **F**=0.86, **p**=0.48). Post hoc analysis revealed in the placebo group that DPOAE amplitudes were reduced 1 and 16 h after exposure compared with the baseline values (**p**<0.05). In the Q-Ter. group, however, DPOAEs did not show any significant difference between baseline and post-exposure amplitudes (**p**>0.1). No significant differences between the two groups in DPOAE amplitude at any of the tested frequencies were present before noise trauma. One hour after exposure, the subjects in the placebo group showed a significant decrease in DPOAE amplitude for f2 values of 3174, 4004, 5042, and 6348 Hz compared with the subjects treated with Q-Ter. (**p**<0.05); 16 h after sound exposure a significant reduction in amplitude was observed in the placebo group for high frequencies (f2: 5042, 6348; **p**<0.05); and 7 and 21 days after exposure no significant differences were highlighted among the subjects treated with Q-Ter. and placebo (7 days: **p**=0.085, 21 days: **p**=0.56). The test-retest performed after a 1-minute interval under all test conditions did not show intra-subject variability. PTA threshold values in the Q-Ter. and placebo groups did not differ from the pre-treatment and pre-exposure values (PTA ≤10 dB). No differences were found between Q-Ter. and placebo treatments before and 1 h, and 7 days after loud sound exposure (**p**>0.05).

### Blood antioxidant and inflammatory markers

The blood markers were analyzed in each study subject before and 2 and 24 h after noise exposure. Among the inflammatory markers, no significantly different levels were observed in the treated and placebo groups in the dosage measured at different time points. The homocysteine levels were higher in the Q-Ter. group than in the placebo group, with no change over time (**F**=37.098, **p**<0.001). No difference could be found between the two groups before and after exposure (**F**=0.0781, **P**=0.925). Other inflammatory markers, such as serum amyloid A lipoprotein (a), ceruloplasmin, and C-reactive protein, revealed no significant alterations between the two groups or before and after sound exposure (**P**>0.1). Oxidative stress markers were also analyzed before and after noise exposure, revealing a significantly lower concentration of nitrites in the patients treated with Q-Ter. than in the subjects in the placebo group (**F**=35.23, **p**<0.001); nevertheless, no significant difference between the groups before and after sound exposure was observed (**F**=0.654, **p**=0.551).

In addition, the total antioxidant capacity (TEAC assay) of blood plasma did not differ among the subjects in the two groups nor before and after noise exposure (**p**>0.1). Participants in the Q-Ter. group showed a lower blood concentration of CoQ10 before and 2 h after loud sound exposure compared with the placebo group; in contrast, an increase in CoQ10 was observed 24 h after noise exposure in the subjects treated with Q-Ter. to a value higher than the subjects in the placebo group. The changes were not significant (**F**=1.567, **p**=0.218). Vitamin E was also analyzed in these groups; no significant alterations in its blood levels were observed between the two groups or before and after sound exposure (**p**>0.1).

## DISCUSSION

In this study, loud sound exposure in volunteer subjects caused a depression of OHC function that resulted in a significant reduction of DPOAEs during the first 16 hours after noise exposure. The DPOAE amplitude values were significantly increased by the intake of Q-Ter. for 7 days before exposure. However, no significant PTA variations were observed by pure-tone audiometry. One of the aims of this study was to investigate the effectiveness of OAE-based tests for the detection of very low levels of hearing loss induced by loud sound as a model of moderate noise exposure in workers. In several other studies, DPOAEs have been found to be more sensitive than pure-tone audiometry, although these data remain controversial. For several authors, although OAEs are a fast, objective, and easy-to-perform test to detect early cochlear damage in NIHL, intra-individual variability and high false-positive rates limit their use for hearing preservation programs (Chan et al. 2004; Shupak et al. 2007). Lapsley-Miller et al. (2006) demonstrated OAE sensibility to aircraft noise exposure with poor correlation of OAE amplitudes and audiometric threshold shifts. Cross-section statistical studies showed that both transient evoked otoacoustic emission (TEOAE) signal-to-noise ratio (SNR) and DPOAE levels were able to discriminate between normal hearing and hearing-impaired ears (Attias et al. 1995; Lucertini et al. 2002). The sensitivity of TEOAEs was good for frequencies below 2 kHz, while DPOAEs were more sensitive for higher frequencies (Sisto et al. 2007; Gorga et al. 1993). Also, the correlation with pure-tone audiometry was significantly better for DPOAEs than TEOAEs. Finally, the effects of inter-individual variability seem to interfere with DPOAEs less than TEOAEs at low levels of NIHL (Sisto et al. 2007). In our study, DPOAEs were repeated twice and only those without signify cant changes in the DPgram waveform were accepted. However, the increased knowledge of the cochlear mechanisms involved in OAE generation minimizes the effects of this variability introducing appropriate data acquisition and analysis procedures. Vinck et al. (1999) analyzed the hearing function in humans before and after visiting a discotheque and found that pure tone audiometry completely recovered after the temporary threshold shift (TTS), whereas TEOAEs and DPOAEs did not recover completely to the pre-exposure reference levels, indicating a higher sensitivity to cochlear damage. Kramer et al. (2006) studied subjects exposed to loud music and found no statistically significant differences between participants who received N-L acetylcisteine (NAC) compared with placebo. The authors found a pure-tone threshold shift at 4 kHz; however, DPOAE reductions were mainly seen at 3 kHz. Our preliminary data confirm the sensitivity of DPOAEs for frequencies higher than 3 kHz, although we did not find significant changes with PTA; this result could be due to the different noise exposure protocols used compared to the previous studies. A recent study conducted in a group of volunteers exposed to impulse noise confirms the sensibility of OAEs, suggesting that low-level OAEs indicate an increased risk of future hearing loss (Marshall et al. 2009). Although DPOAEs seem to be a helpful method that provides additional information on cochlear function compared with pure-tone audiometry, an additional aim of this study was to evaluate whether DPOAEs could be effective in monitoring the effects of an antioxidant drug (Q-Ter.) that was previously studied in our laboratory I a guinea pig animal model of NIHL, demonstrating a significant protective effect against noise-induced hearing loss. In this study we compared the effectiveness of CoQ10 with a soluble formulation of CoQ10 (multi-composite CoQ10 terclatrate Q-Ter.) in an animal model of acoustic trauma. Drugs were given intraperitoneally 1 hour before and once a day for 3 days after pure-tone noise exposure (6 kHz at 120 dB SPL for 1 hour). The treatments attenuated NIHL as measured by ABR and decreased active caspase 3 expression and the number of apoptotic cells. Animals injected with Q-Ter. showed a greater degree of activity in preventing apoptosis and thus in improving hearing (Fetoni et al. 2009). As also confirmed in this animal study, the mitochondrial respiratory chain is a powerful source of ROS in NIHL and antioxidants and free-radical scavengers have been shown to attenuate the damage. Coenzyme Q10 (CoQ10), or ubiquinone, has a bioenergetics role as a component of the mitochondrial respiratory chain, inhibits mitochondrial lipid peroxidation, induces ATP production, and is involved in ROS removal and prevention of oxidative stress-induced apoptosis. However, the therapeutic application of CoQ10 is limited by its lack of solubility and poor bioavailability; therefore it is a challenge to improve its water solubility in order to ameliorate the efficacy in tissue and fluids. The multi-composite Q-Ter. formulation is highly soluble and spreads in water, forming a milk-like suspension. By definition, in a multi-composite material the chemical moieties of the starting materials are preserved, while physicochemical properties, such as solubility, stability, and dissolution rate, are improved. CoQ10 is well known as a practically in- soluble substance with very poor bioavailability and low stability problems; it is also diffi cult to handle due to its wax-like properties. In the multi-composite Q-Ter., CoQ10 has been treated in association with a suitable carrier material (cyclodextrin) and a bioactivator, the amino acid glycine. The resulting multi-composite has proven to be about 200 times more soluble and to retain its antioxidant capacity (Ou et al. 2001) more than 5 times compared to the native CoQ10 (Corvi Mora et al. 2007). This study was performed in a small number of volunteers and, although it represents a preliminary report, it also provides encouraging data for future use in a larger clinical trial. Q-Ter. administered before noise exposure prevented the initial OHC pathology as revealed by DPOAEs 1 and 16 hours after noise exposure. No significant modifications were observed between the Q-Ter. and placebo participants 7 and 21 days after sound exposure; this could be explained by the lower dosage used in the days following exposure, which could be insufficient for long-term protection. In addition, many experimental data demonstrated that the therapeutic window for a successful antioxidant approach in NIHL occurs within the first ten days after noise exposure. For these reasons, future studies are recommended to test higher Q-Ter. doses for a longer time. In the last decade, extensive literature confirms that increasing antioxidant levels in the organ of Corti represents a rational approach against NIHL. This can be done by increasing the endogenous antioxidant response or by administrating antioxidant molecules systemically or locally (Henderson et al. 2006). Many antioxidant agents have been successfully tested in numerous experimental models, such as glutathione, GluR-phenylisopropyladenosine (R-PIA) (Hu et al. 1997), D-methionine (Campbell et al. 2007), ebselen (Lynch et al. 2004), allopurinol (Seidman et al. 1993), resveratrol (Seidman et al. 2003), and dietary supplementation of vitamin C, vitamin A, idebenone, and vitamin E, which is considered one of the most effective antioxidants used in experimental models (Le Prell et al. 2007; Fetoni et al. 2008). The efficacy of N acetil-cysteine, a free-radical scavenger, seems to be related to the dose and schedule of administration in rats (Lorito et al. 2008) and its effects seem to be enhanced by noise conditioning (Lorito et al. 2008). Kopke et al. (2007) reported preliminary data on the protective effects of NAC in soldiers exposed to noise during the Iraq War (unpublished paper), while Kramer et al. (2006) did not show significant NAC protection in a group of volunteers exposed to loud music in a discotheque. Coenzyme Q has been proposed for the treatment of cardiac, neurological, oncologic, immunological, and neurodegenerative diseases. Angeli et al. (2005) reported that CoQ10 may be helpful in delaying the progression of hearing loss in patients with the 7445A®G mitochondrial mutation. The soluble formulation of Q10, Q-Ter., has a higher bioavailability and different pharmacokinetic properties and has been considered a safe molecule for clinical treatment. In this preliminary study we also tested inflammatory and oxidative stress markers in all participants. The blood parameters were investigated firstly to exclude toxic effects of Q-ter during treatment and secondly to evaluate whether plasma antioxidant and inflammatory activity could be used to monitor noise-induced damage and prevention. The role of inflammation in NHIL remains controversial and the protective effects of steroids such as dexamethasone, one of the major anti-inflammatory drugs, still have to be precisely identified (Le Prell et al. 2007; Bas et al. 2008). It is well known that oxidative stress is implicated in OHC damage, although there is no evidence of a correlation between oxidative damage to the cochlea and the antioxidant system in the blood. In a previous paper, lower levels of systemic CoQ were found in patients with sudden sensorineural hearing loss, thus suggesting a role as a marker of oxidative stress in the inner ear (Cadoni et al. 2007). In our experimental groups, CoQ levels were significantly higher in the subjects treated with Q-Ter. 24 hours after exposure compared with the placebo group; the levels were not elevated 2 hours after exposure. However, vitamin E, another important marker of the endogenous antioxidant system, was not significantly modified in the two groups. These changes in antioxidant system-related markers suggest that a longer administration of the drug could increase the blood concentration of CoQ and thereby result in better long-term protection. Among the other blood markers studied in the two groups before and after trauma, no significant changes could be seen in inflammatory markers such as homocysteine, amyloid A, lipoprotein (a), ceruloplasmin, and C-reactive protein nor in oxidative stress markers such as nitrites and total antioxidant capacity (TEAC assay), proving that Q-Ter. did not interfere with the systemic concentrations of anti-inflammatory and antioxidant markers and that they cannot be directly related to cochlear damage or used to monitor noise-induced damage and prevention. CoQ levels were slightly but not significantly increased in the Q-Ter.-treated group 24 h after loud sound exposure. The reason why this parameter was augmented needs to be explained and more data concerning the bioavailability and pharmacokinetic of Q-Ter. could be helpful. The difference could depend on the dosage or on the tissue entrance of the agent that improves the bioenergetics in the cochlea during and after stress. In previous experimental models it was demonstrated that the “therapeutic window” for the antioxidant therapy could be within the first two weeks after trauma [6]; for this reason the authors propose to study Q-Ter. at different doses and schedule of administration in a future paper.

This pilot study confirms that DPOAEs represent a sensitive test for monitoring both the effects of noise in preclinical conditions and pharmacological treatment; however, the measurement of blood parameters of inflammation and oxidative stress cannot discriminate between untreated and treated subjects. The preliminary data presented in this study are encouraging for a larger clinical trial to collect additional evidence on the effect of Q-Ter. in preventing NIHL development in subjects exposed to noise.

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# Comparison of hearing loss in elderly with and without history of occupational noise exposure

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## ABSTRACT

The multiplicity of metabolic and circulatory alterations related to noise may cause the onset of several symptoms, including hearing loss. The purpose of the study was to assess the prevalence of hearing loss in elderly with and without history of occupational noise exposure. A cross-sectional study was realized in a population sample with 399 individuals aged over 60 years in Londrina - Brazil, through anamnesis and audiological evaluation. The variables studied were frequency of hearing loss and history of occupational noise. Non-conditional logistic regression was used in order to control likely confusion or modification of effect to the other variables on interest associations. Hearing loss was reported in 84.31 % of cases, elderly with history of occupational noise exposure and in 63.80 % of controls, elderly without history of occupational noise exposure. A high frequency of hearing loss was detected in the population under investigation, with significantly statistic difference between the presence of hearing loss and history of occupational noise. There were no differences in the laterality of the first affected ear. In the population with hearing loss, the study suggests that the history of occupational noise exposure is accelerating degeneration factor of the hearing apparatus. The result in this research, through evidence of association between history of occupational noise and hearing loss, can allow for an integrated work of health professionals concerned with alterations caused by occupational noise.

## INTRODUCTION

The multiplicity of metabolic and circulatory alterations related to noise may cause the onset of several symptoms, including hearing loss with onset slow and progressive. Subjects with Noise-Induced Hearing Loss (NIHL) have frequently several symptoms such as tinnitus, vertigo, gradual decrease or distortion in sound and alterations in speech comprehension. The NIHL is irreversible and permanent but it is preventable by use of hearing protectors when exposed to noise. The magnitude of hearing loss results from excessive exposure to noise and depends on factors associated with the exposure, sound pressure level, duration, type of noise, frequency, and the characteristics of the individual being exposed, susceptibility to NIHL, age, prior history of hearing damage. Besides occupational exposures, hearing loss has been associated with smoking, diabetes, hypertension, aging, health history and activities leisure-time (Marchiori et al. 2006; Agrawal et al. 2009; Collee et al. 2011).

The incidence of hearing symptoms in the ear seems to be correlated with the noise exposure during entire life (Jokitulppo et al. 2005).

Presbyacusis can be defined as the hearing loss associated with aging. Presbyacusis reflects the loss of hearing sensitivity associated with advanced aging and is the third most common chronic condition reported by the elderly people (Lethbridge-Cejku et al. 2004).

The typical audiometric profile observed clinically in presbyacusis is a bilateral symmetric high-frequency sensorineural hearing loss that progresses with advancing age (Krishnamurti 2009).

The first sign of hearing loss from noise exposure is a notching of the audiogram at 3,000, 4,000, or 6,000 Hz, with recovery at 8,000 Hz. In early stages of NIHL, the average hearing thresholds at 500, 1,000, and 2,000 Hz are better than the average at 3,000, 4,000, and 6,000, and the hearing level at 8,000 Hz is usually better than the deepest part of the notch. This notch is in contrast to age-related hearing loss, which also produces high frequency hearing loss, but in a down-sloping pattern without recovery at 8,000 Hz (Krishnamurti 2009).

Data from the gerontological and geriatric population study of Gothenburg, Sweden, indicates that the age-related deterioration of the frequencies 1, 2 and 8 kHz is more pronounced in elderly men exposed to noise compared with those not exposed to noise from age 70 to age 75 (Gates et al. 2000).

However, one of the limiting factors of differential diagnosis sensorineural hearing loss in the elderly is that typically age-related hearing loss tends to be confounded by previous effects of noise exposure in those individuals employed previously in a noisy workplace environment. Sensorineural hearing loss related to noise exposure typically does not produce a loss greater than 75 decibels (dB) in high frequencies and 40 dB in lower frequencies. Noise-induced hearing losses along with superimposed age-related losses may have hearing threshold levels in excess of these values (Krishnamurti 2009).

A lifetime of exposure to noise increases the probabilities of negative effects on hearing, but is difficult to determine the interaction between noise-induced hearing loss (NIHL) and age-related hearing loss. Age-related hearing loss has a complex etiology including both intrinsic and extrinsic factors. The influence of noise on presbyacusis has been postulated in numerous reports for almost a century. However, it is difficult to identify one single factor to the effects of prolonged noise exposure, with duration of many decades. The effect of noise is equivocal. The interactions between noise-induced hearing loss and age-related hearing loss are complex, difficult to determine, and poorly understood. One major problem is that age related hearing loss is extremely multifactorial (Rosenhall 2003).

In review with compilation of 11 investigations by different authors regarding the progression of hearing deterioration during severe long-term exposure to noise in mines, shipyards, forges, weaving mills, other factories and industries and from field artillery and hunting, with one exception, the reports concern conditions at times when ear protection was virtually unknown or only seldom used. The different investigations are described in a broad outline with their essential measurement and background data. Despite the great diversity in the character and level of the noise, the compilation shows for the higher ages in the range of 3 to 8 kHz a similar median hearing loss from nearly all investigations; however, at 1 kHz and, particularly, at 2 kHz the differences in the character of the noise are apparent in a wide spread of the median hearing loss between the different studies. In addition, it was found that at higher ages and hearing loss levels of more than 45 to 50 dB it is not possible to distinguish between the effect of the noise, on the one hand, and that of ageing, on the other; the ad hoc assumption of their additivity is no longer valid and thus the term age correction inadequate (Rosler 1994).

Many authors have considered hearing loss related to presbyacusis as result of various negative extrinsic and intrinsic factors. As a polycausal chronic disease it is difficult to define hearing loss in the elderly as a decline in auditory sensitivity caused only by age-related degeneration. In a Brazilian Study the prevalence of hearing loss was significant and in accordance with other relevant international epidemiological studies (Mattos & Veras 2007).

Noise-induced hearing loss is a major cause of deafness and hearing impairment in the United States (Daniel 2007). Hearing loss caused by exposure to recreational and occupational noise results in devastating disability that is virtually 100 percent preventable. Noise-induced hearing loss is the second most common form of sensorineural hearing deficit, after presbyacusis. Noise-induced hearing loss can be prevented by avoiding excessive noise and using hearing protection such as earplugs and earmuffs. Patients who have been exposed to excessive noise should be screened. When hearing loss is suspected, a thorough history, physical examination and audiometry should be performed. If these examinations disclose evidence of hearing loss, referral for full audiologic evaluation is recommended (Rabinowitz 2000).

The study by Krishnamurti indicates that the effects of noise exposure on hearing varied across age-groups and highlights the importance of applying age- and gender-corrections prior to determining the relative contribution of occupational noise exposure in patients with SNHL. This suggests more research to address the weighted contributions of aging and noise effects in the occupation NIHL population (Krishnamurti 2009).

In an epidemiological search of elderly persons Pratt et al. (2009) have studied the impact of age, gender, and race on the prevalence and severity of hearing loss in elder adults, aged 72–96 years, after accounting for income, education, smoking, and clinical and subclinical cardiovascular disease. Hearing loss was more common and more severe for the participants in their 80s than for those in their 70s—the men more than the women and the White participants more than the Black participants. The inclusion of education, income, smoking, and cardiovascular disease (clinical and subclinical) histories as factors did not substantially impact the overall results. They suggested that hearing loss is more substantial in the 8th than the 7th decade of life and that race and gender influence this decline in audition. Given the high prevalence in the aging population and the differences across groups, there is a clear need to understand the nature and causes of hearing loss across various groups in order to improve prevention and develop appropriate interventions (Pratt et al. 2009).

The possible correlations between hearing function and history of occupational noise exposure in elderly reveals a complex situation, considered the multitude of intrinsic and extrinsic etiologies associated with age.

The purpose of the study was to assess the prevalence of hearing loss in elderly with and without history of occupational noise exposure.

## METHODS

A cross-sectional study was carried out at UNOPAR in Londrina, Brazil. The study protocol was approved by the bioethical committee of the UNOPAR University. This was the first large rigorous survey to examine 500 elderly in the city concerned. The subjects were sent by EELO project. The total population of this study consisted of sample of 399 first elderly evaluated. Individuals aged over 60 years with and without history of occupational noise exposure, evaluated through anamnesis and audiological evaluation (798 ears).

The anamnesis included questions about age, gender, hearing loss complaint, related noise exposure history and medical history. The audiological evaluation was performed individually in a sound-proof booth with an Interacoustics Audiometer.

The variables studied were frequency of hearing loss and history of occupational noise. Mean values and standard deviation were used as descriptive statistics. To select the variables in order of their P-values, it was performed association statistic, applying the chi-square test and logistic regression, represented by values of odds ratio (Odds Ratio - OR) and their respective confidence intervals 95%. The logistic regression was used in order to control confusion or modification of effect to the other variables on interest associations. The procedures were performed using SPSS software, version 10.0, adopting a significance level of 5 %.

## RESULTS

The total study population consisted of a sample of 399 first elderly evaluated. Hearing loss was reported in 84.31 % of elderly with history of occupational noise exposure and in 63.80 % of elderly without history of occupational noise exposure.

A high frequency of hearing loss was detected in the population under investigation, with significantly statistic difference between the presence of hearing loss and history of occupational noise. There were no differences in the laterality of the affected ear. The symmetrical hearing loss was the most frequent form in elderly without history of occupational noise exposure and the asymmetrical hearing loss was the most frequent form in elderly with history of occupational noise exposure. The asymmetrical hearing loss was the most frequent in the male compared to the female. The history of occupational noise and male gender proved to be independent risk factors for hearing loss.

**Table 1:** Hearing loss and history of occupational noise exposure – total sample

| | | Hearing loss | | | |
|---|---|---|---|---|---|
| With history of occupational noise exposure | | Yes | | No | |
| | | n | % | n | % |
| Yes | (204 ears) | 172 | 84.31 % | 32 | 15.68 % |
| No | (594 ears) | 379 | 63.80 % | 215 | 36.19 % |
| Total | (798 ears) | | | | |

$\chi^2 = 78$ (p<0.0001)

**Table 2:** Logistic regression analysis of hearing loss and independent variables

| Effect | Degree of freedom | Wald | p |
|---|---|---|---|
| Intercept | 1 | 21,54508 | 0,000003 |
| Gender | 1 | 5,77976 | 0,016212 |
| Noise exposure | 1 | 6,36951 | 0,011610 |

This analysis suggests that independent variables were significant predictors. The history of occupational noise and male gender proved to be independent risk factors for hearing loss.

According to other studies, the search present shows interaction between hearing loss and history of occupational noise exposure.

Gates et al. (2000) describe that a lifetime of exposure to noise is likely to have negative effects on hearing, but the interaction between noise-induced hearing loss (NIHL) and age-related hearing loss is difficult to determine. The most commonly accepted assumption is a simple accumulating effect of noise and ageing on the hearing. However, both a less than additive effect as well as a supra-additive effect has been proposed. Recently an interesting interaction between NIHL and age-related hearing loss has been reported.

Another study indicates a pronounced difference between 70-year old men exposed to massive occupational noise, compared to a control group. This difference was not confined only to the NIHL-area, but also at 1 and 2 kHz. The most profound deterioration of the hearing between age 70 and age 75 was found at the frequency 2 kHz for both men exposed and not exposed to noise, but the deterioration was much more pronounced for the exposed group, the difference being more than 1 dB per year. The deterioration was considerably less at the NIHL frequency 4 kHz. The reduced deterioration was about the same for both groups at this frequency. The annual deterioration was much less for all frequencies with no apparent difference between the two groups between age 75 and 79 (Rosenhall 2003).

## CONCLUSIONS

The prevalence of hearing loss in the elderly with and without history of occupational noise exposure in present search was high, in accordance with others epidemiological studies.

The limitation of this present study is its reliance on self-reported information over exposure to noise in a retrospective way because no objective measures were possible in elderly sample. In addition, this study did not control the confounding factor of noise intensity with history of occupational noise, which may affect the interpretation of results. Hence, these values need to be interpreted with caution.

According to other studies the symmetrical curve was the most frequent form of hearing loss in elderly without history of occupational noise exposure, which suggests that hearing loss was related to age. There was a higher rate of asymmetrical hearing loss in the case group compared to the control group; this could be explained by a greater exposure of cases to noise at work. Both the history of occupational noise and the male gender proved to be independent risk factors for hearing loss.

This study shows difficulty of investigating the relationship between history of occupational noise and age-related hearing loss in elderly. However, a high frequency of hearing loss was detected in the population under investigation, with significantly statistic difference between the presence of hearing loss and history of occupational noise, reflecting the association between histories of occupational noise and hearing loss. Based on results of the current study an integrated work of health professionals concerned with alterations caused by occupational noise is recommended.

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# Using multiple media outlets to enhance a community based noise-induced hearing loss prevention program

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## INTRODUCTION

While hearing loss can affect people of all ethnic groups, native Americans have twice the moderate to severe hearing loss of Caucasians (Barnes et al. 2005). It is thought that noise-induced hearing loss (NIHL) may play a significant role in this degenerative process. However, hearing loss prevention programs in tribal communities have been lacking (Martin et al. 2008a). To this end, a CDC-funded Prevention Research Center, the Oregon Health & Science University Center for Healthy Communities, has begun a project called “Listen for Life” aimed at reducing NIHL in Northwest tribal communities. In this effort, multiple health communication strategies are applied in the context of a community-based participatory research model (Minkler & Wallerstein 2008).

The effectiveness of a hearing loss prevention program is, in large part, dependent upon its cultural relevance to the intended target audience, and its concordance with the normative expectations in the target community (Martin et al. 2006, 2008b; Sobel & Meikle 2008). To be effective, interventions in a tribal community must reflect the tribal social norms in all respects. It is, therefore, critical to partner with a local community advisory group on message design and content. This paper will address the use of media messages created by this partnership and used as part of a larger effort that included a school-based prevention program (Dangerous Decibels®) and a community event.

### Increasing awareness and salience in the community

McCombs & Shaw (1972) suggest that the mass media messages tell us “what issues to think about, not what to think about the issues.” In other words, mediated messages that are printed or broadcast can effectively create a level of issue awareness and salience in a community. Individuals denote importance to issues they are exposed to over a period of time (McCombs 2005). The theory of “agenda setting” assumes that we tune into messages that we have identified as important (or salient) and we tune out other messages. Salience may result from one media source that the population is regularly exposed to, or many media sources that present similar stories over time. The communication literature has long accepted that exposure to issue-oriented mediated messages can create awareness and salience in a community (McCombs & Shaw 1972). Research regarding the agenda-setting theory has shown that issue awareness and salience can be created by messages specifically designed to identify healthy and unhealthy behaviors, as demonstrated in the arena of HIV/AIDS (Rogers et al. 1991) and drug abuse (Cappella et al. 2001). In this regard, the theory suggests that individuals are more likely to attend to information about hearing loss prevention, if they have been exposed to multiple media messages on this topic, particularly if these messages are culturally and socially relevant.

## METHODOLOGY

In the United States, a tribal reservation community represents a setting that is inclusive and self-governing, in which the control of media, education, and health care is localized and overseen by the tribe's governance structure of a council and executive agencies. Within this unique environment, the "Listen for Life" project utilized broadcast, print, and web sources, over several months, to enhance the community effort to decrease NIHL in the population. These messages provided multiple opportunities for educational exposure to the issue. The educational messages were broadcast at regular intervals throughout the longer study period.

Human-interest and informational stories were broadcast to create awareness about the dangers of loud sounds, to increase the perception of salience surrounding this issue in the community, and to educate the population about the causes of NIHL and practical preventive measures. Messages were aired and published in a sequence that was designed to compliment other components of the hearing health promotion intervention including the Dangerous Decibels® classroom program, an evening outreach event open to all community members and the use of a web-based learning program. Exposure to the messages began in September before the school-based program, and ended in November, after the other interventions had been delivered.

Vignettes were created of tribal members who had hearing loss and/or tinnitus (chronic ringing in the ears) and of other members who had relatives with hearing problems. Teens were also interviewed and asked about their attitudes and behaviors regarding hearing and hearing loss. With the assistance of the Advisory group, human-interest stories and video segments were created. Four newspaper articles were published over the course of 2 months in the community bi-monthly newspaper. These consisted of a combination of vignettes, and educational and informational messages. The printed newspaper was also posted on the local community website. In addition, a five-minute video consisting of segments of interviews and topical music was produced and downloaded to the website. Flyers with a tribal theme were created, published and distributed in local community establishments.

Over the past 20 years, "Indian Radio" has developed into a substantial communications net for Indian Country (Robbins 2001), and provides programming and talk forums for local communities. In our intervention, the local tribal radio station broadcast a series of "fun factoids" (supplied by the university staff) about hearing loss and hearing loss prevention, many times over the course of 2 months. Also, just prior to the school program and community event, the radio station aired an interview with an expert in hearing loss prevention (Principal Investigator, Dr. William Martin).

## PRELIMINARY RESULTS

At the conclusion of the first year of this multi-year program, media message evaluation is limited. One exception to this is the existence of data collected at the large community event (a component of the "Listen for Life" comprehensive project). The evening event was well publicized in the newspaper, on the radio, on the website, and on flyers that were distributed at community establishments. Tribal members were asked where they read or heard about the event. The survey revealed that 35 % of the adults heard or read about it in the media. About the same proportion (35 %) of participants heard about the program from their children who participated in the classroom training in the schools. Many of the participants reported that they had heard about the evening event interpersonally, while talking to others (which may also be related, indirectly, to the media campaign).

In addition, the classroom program results are currently being analyzed. The results to date look very promising, and they will be published in an upcoming paper. While the classroom survey data will reflect the success of the Dangerous Decibels program on 4th and 5th grade students, their parents' exposure to the media messages is intended to increase parent-child communication about hearing loss prevention in the home, potentially reinforcing messages the children received in school and online. An examination of this effect may be possible in upcoming years.

Finally, a community-based participatory program such as "Listen for Life" is dependent upon community involvement. The success of the project is measured in large part by its sustainability. Media messages that increase awareness and create issue salience bring some community members to the table. They may become vested in the promotion of hearing loss prevention in the tribal community, and become part of its continuation.

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# Hearing thresholds of young workers and conscripts in Switzerland

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## INTRODUCTION

In the past decades, considerable efforts have been made to reduce noise in the work environment and improve hearing protection among noise-exposed workers. On the other hand there are concerns about noisy leisure time activities, and an increasing prevalence of noise-induced hearing loss in adolescents is discussed. A recent study in US adolescents (Shargorodsky et al. 2010) showed an increased prevalence of hearing loss in 2005-2006 compared to 1988-1994 but could not show a significant association with noise exposure. In Europe, several studies have been published on the prevalence of hearing loss in young workers (Ising et al. 1988) and in conscripts (Borchgrevink 1998; Job et al. 2000; Jokitulppo et al. 2006; Muhr et al. 2007) and its change over time.

Also in Switzerland, the hearing threshold is routinely tested at conscription for military and in young workers, who will be exposed to high noise levels at work. In order to get a notion of the hearing status of Swiss adolescents, these screening data were analyzed.

There are international standards defining the hearing thresholds to be expected in a population at a certain age for different frequencies. ISO 7029 (2000) describes a screened population without any hearing or ear problems. The thresholds are expressed in dB hearing level (dB HL), whereby 0 dB HL at a given frequency is defined by the sound level half of an 18 year old screened population is able to hear. Distributions of hearing thresholds in different populations can be easily compared.

Hearing loss or hearing impairment on the other hand is defined differently in every publication, which makes a comparison impossible. Hearing loss caused by noise is normally identified by a typical notch at 4-6 kHz in the audiogram.

## METHODS

### Screening data of young workers

Since 1971 hearing of noise-exposed workers is regularly tested by pure tone audiometry. Also young workers, who were not yet exposed to noise at work, are tested. Since 1994 the hearing threshold of each ear is measured at 0.5, 1, 2, 4, 3, 6, 8 kHz starting at 0 dB HL in steps of 5 dB. Before 1994 the test started at 20 dB HL. The test is performed with a manual audiometer in a soundproof cabin with a Sennheiser HDA200 headset since 1998, before with a Telephonics TDH39 headset.

In the period 1971-2010 144,696 subjects (136,489 males, 8,207 females) at the age of 16-20 years were tested, 46,418 (44,627 males, 1,791 females) of them in the period since 1998 with stable measuring conditions.

### Screening data of military conscription

Since 1992 the hearing of the military conscripts is tested by pure tone audiometry. Because the main objective of this screening is the identification of hearing impaired subjects, the test method was not standardized until recently and audiometry started only at 20 dB HL.

Since 2006 hearing threshold of each ear is defined at 0.5, 1, 2, 4, 6, 8 kHz starting at 5 dB HL in steps of 5 dB. The test is performed with an automatic audiometer in a soundproof cabin with a Telephonics TDH39 headset. In the period 1992-2009, 578,806 male subjects were tested, 133,743 of them in the period 2006-2009 with stable measuring conditions.

### Hearing loss, hearing impairment

According to WHO[1] the hearing impairment grade is defined by the average hearing level at 0.5, 1, 2, 4 kHz of the better ear. An average of 25 dB HL or better is defined as normal hearing.

In order to identify a noise induced threshold shift (NITS) the individual audiogram (frequency vs. hearing threshold) of each ear is evaluated. A NITS is defined as an audiogram pattern that meets the following criteria for at least one ear (Shargorodsky et al. 2010): hearing threshold (HT) at 0.5 and 1 kHz < 15 dB HL; maximum HT at 3, 4 or 6 kHz at least 15 dB higher than maximum HT at 0.5 and 1 kHz; HT at 8 kHz at least 10 dB lower than the maximum HT at 3, 4 or 6 kHz.

The detection of NITS depends strongly on the starting point of the audiogram. The detection of small NITS at a low level is only possible, if the tested subject is not able to hear the lowest sound-level of the audiometric test. In order to compare data with different starting points, the following simple definition for a high-frequency (HF) hearing loss was used: hearing threshold at 4 or 6 kHz > 25 dB HL, hearing threshold for other frequencies ≤ 25 dB HL.

### Average audiogram

For the average audiogram the hearing threshold at each frequency is averaged over both ears of the subject. The quantiles (10 %, 50 %, 90 %) of the distribution are determined for each frequency and displayed as an audiogram of a population.

## RESULTS

According to the definition of WHO, 98.7 % of the conscripts (period 2006-2009) and 99.6 % of the young workers (period 1998-2010) have normal hearing.

Figure 1 shows the fraction of subjects with a high-frequency hearing loss in both ears and its change over time. A decline from about 15 % in the seventies to about 2 % in the last decade can be observed. The fraction in conscripts is comparable for the last years with about 2 %.

Figure 2 shows the fraction of young workers with a noise-induced threshold shift. Over the period the fraction is almost stable at about 20 %.

[1] http://www.who.int/pbd/deafness/hearing_impairment_grades/en/index.html (visited 13.5.11)

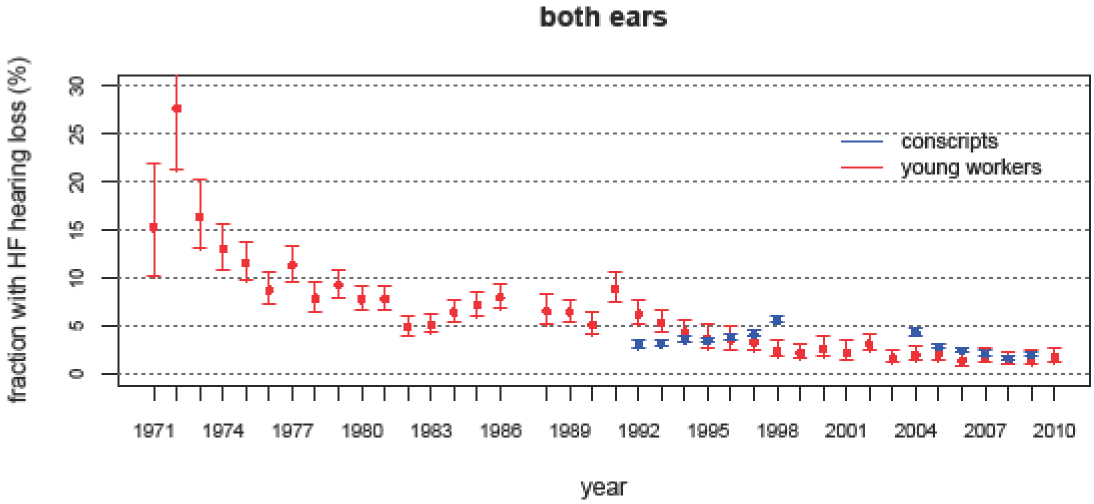


**Figure 1**: High-frequency hearing loss in young workers and conscripts

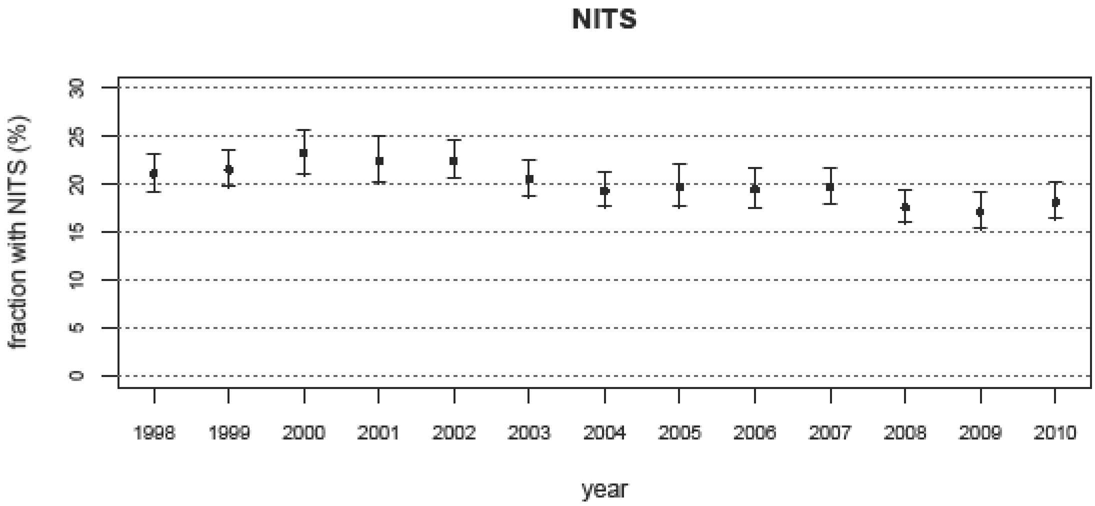


**Figure 2:** Noise-induced threshold shift in young workers

Figure 3 shows the average audiograms of young male workers (period 1998-2010) of different age. The 10 % and 50 % quantiles of the distribution differ from the ISO 7029 distribution of a screened male population. The 90 % quantile differs only at high frequencies from the standard. For all quantiles, a marked dip at 6 kHz can be observed. Contrary to the ISO 7029 standard, where the hearing threshold distribution does only change minimally between the age of 18 and 20 years (< 1dB), in the young workers a worsening of the hearing with age can be observed. For 10 % of the population with the poorest hearing the decrease between 16 and 20 years is 5 dB for 6 kHz and 2.5 dB for the other frequencies.

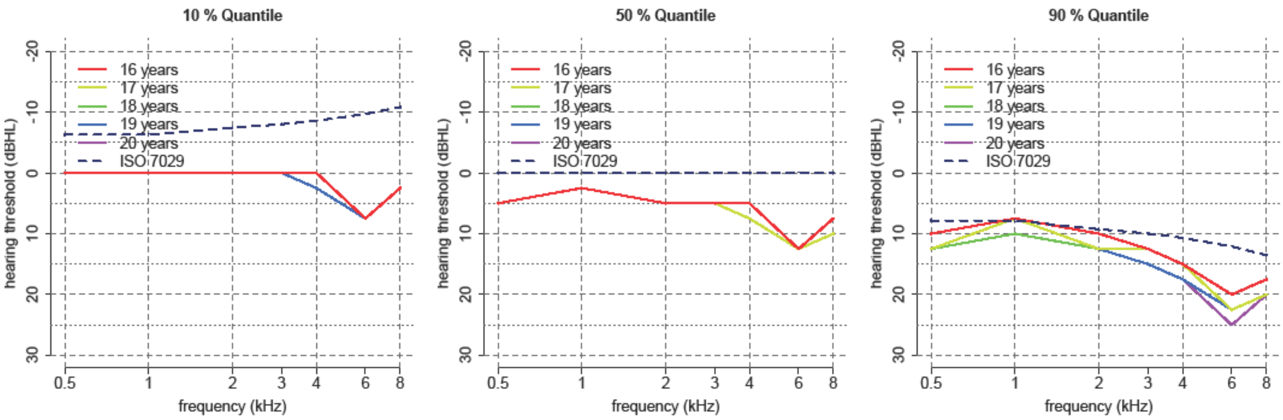

**Figure 3**: Average audiograms: Quantiles of young male workers and corresponding ISO 7029 curves

## DISCUSSION

Swiss adolescents have a good hearing according to WHO criteria. The observed decrease in high-frequency hearing loss over the last 40 years might be explained by an increased awareness in the population and sound level limits not only at workplaces but also for music events and in personal music players. Also an improvement in overall health (e.g. less untreated middle ear infections) could have had an effect on the hearing. Nevertheless one has also to keep in mind that the measurement conditions changed over the years, which can strongly influence the results.

The fraction of subjects with NITS strongly depends on the measurement parameters. Because the definition of NITS depends mainly on the shape of the audiogram, the fraction of subjects with NITS depends on the starting point of the audiometric test. Because of the dependence on the hearing threshold at 8 kHz, the fraction of subjects with NITS is high in a young population because of a good hearing at 8 kHz. Also the dependence on the low-frequency hearing threshold can distort the result because it can be influenced by ambient noise and the soundproofing of the cabin. Because of that, the fraction of 20 % NITS in young workers can not be compared to the fraction of 5 % in conscripts, because in the audiometric test for the conscripts the starting point is 5 dB higher and the ambient noise is elevated.

The distribution of the hearing thresholds at different frequencies, the average audiogram, shows a poorer hearing of the young workers compared to the ISO 7029 distribution. ISO 7029 represents a screened population without any ear problems, so any unscreened population as the workers is expected to have poorer hearing. For the 10 % and 50 % quantiles, the starting point of the audiometric test at 0 dB HL instead of -10 dBHL is a severe limitation. The observed dip at 6 kHz is a known problem of the ISO 7029 standard itself (Smith et al. 1999). In the 10 % with poorest hearing (90 % quantile), a much stronger worsening of the hearing with age is observed than expected. This group might be an especially vulnerable population.

Overall it has to be kept in mind that the evaluated data in this study were historical screening data that were collected for a different purpose. It has been suggested (Augustsson & Engstrand 2006) that in screening data the hearing thresholds are elevated compared to regular audiometry.

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# Vuvuzelas at South African soccer matches: risks for spectators' hearing

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## ABSTRACT

South African Premier Soccer League (PSL) matches are known worldwide as some of the noisiest recreational events. Therefore, the objectives of this study were to i) measure noise levels during different PSL matches; ii) measure changes in auditory function after attending PSL matches; and iii)determine the factors that increase the risk of overexposure to noise during PSL matches. The study used a descriptive quantitative analytical pre- and post-exposure design. Participants (*n*=19 and *n*=10) attended two PSL matches. Each participant's auditory function was assessed using distortion product oto-acoustic emissions (DPOAEs) before and after attending a PSL match. Peak sound pressure ($L_{Cpk}$) and equivalent continuous ($L_{Aeq}$) levels as well as noise dose were measured during each match. Noise levels recorded during the poorly attended Match 1 were lesser than those of the well-attended Match 2. Participants attending Match 2 had statistically significant reduction in their DPOAE amplitudes after the match ($p$=0.003) than those attending Match 1. *Vuvuzela* blowers and participants seated within 1 m from them were most at risk of harm to their hearing with significant reduction in DPOAE amplitudes post the match ($p$=0.002 and $p$= 0.008, respectively). It was therefore concluded that noise levels at well-attended South African PSL matches pose a significant risk to spectators' auditory function as shown by reduced DPOAE amplitude post match attendance. Three risk factors for overexposure to noise during the match were identified: blowing the *vuvuzela*, close proximity to the individual blowing the *vuvuzela* as well as spectator turnout at the match.

***Keywords:*** *Distortion product oto-acoustic emission, noise exposure, noise-induced hearing loss, soccer match, vuvuzela*

## INTRODUCTION

The effects of exposure to loud noises on hearing have been known for centuries, with some of the earliest reports linking noise exposure to hearing loss dating back to the early 1800s (Fosboke 1831; Holt 1882). Much of what is currently known about the effects of exposure to noise on hearing is based on investigations of occupational noise, and less is known about the consequences of other sources of noise. The general public is being increasingly exposed to noise, suggesting that excessive noise exposure will continue to be a major public health concern in the 21$^{st}$ century (Passchier-Vermeer & Passchier 2000).

Modern hobbies such as sporting activities, rifle shooting, and use of personal stereos (under earphones) are known to expose individuals to high levels of noise that may have adverse effects on their hearing and quality of life. In South Africa, soccer matches, in particular, are under the spotlight as social events that expose the public to potentially harmful noise levels. The biggest contributor to noise levels in soccer stadiums across South Africa is the *vuvuzela*, a trumpet-like instrument that is often blown by fans during matches (Staff Writer 2009). The noise made by this instrument has a broad frequency spectrum between frequencies 250 and 8,000Hz, with almost equal energy across all the frequencies (Swanepoel et al. 2010). A recent study by Swanepoel & Hall III (2010) provided the first empirical evidence linking the noise emitted by the *vuvuzela* during football matches to negative impact on auditory function of those exposed to it.

To minimize the health risks of noise to the workers, noise exposure is legislatively regulated in many occupational settings. Most agencies that regulate occupational noise exposure specify a Criterion Level, which is the maximum permissible exposure to accumulated noise, to be an 8-hour equivalent continuous noise level of 85 dBA (Nietzel et al. 2004). Therefore, any workplace that exposes employees to noise levels ≥85 dBA for 8 hours risks harm to their hearing (South African National Standards [SANS] 2004; International Organization for Standardization [ISO] 1990). Further, the exposure time must be halved for every additional 3 dB increase in the noise level (National Institute for Occupational Safety & Health, NIOSH 1998). For example, at 88 dBA, a safe exposure duration is 4 hours. In terms of the maximum permissible exposure to peak sound pressure, Directive 2003/10/EC of the European Parliament has set a occupational limits for peak sound pressure at 140 dBC for adults (Directive 2003/10/EC), while 120 dBC is the recommended limit for children (Passchier-Vermeer & Passchier 2000). According to Passchier-Vermeer & Passchier (2000), these Criterion Levels can be utilized for social noise exposure. Therefore, for an average soccer match of duration of 2 hours (including half-time interval), equivalent continuous noise levels must be below 91 dBA and peak sound pressure levels should be below 120 dBC to be considered safe for all spectators (adults and children).

There is generally limited research evidence that realistically estimates the extent of noise-induced hearing loss (NIHL) from non-occupational noise exposure and thus the risk of NIHL (Nietzel et al. 2004). Therefore, this study aims to i) measure noise levels during different South African Premiere Soccer League (PSL) games; ii) measure changes in auditory functions after attending a PSL match; and iii) determine the factors that increase the risk of overexposure to noise during PSL matches.

## METHODS

A descriptive analytical pre- and post- exposure design using quantitative methods of data collection was chosen for this study. Ethical clearance was first obtained from the University of Cape Town (UCT), Faculty of Health Sciences Human Research Ethics Committee, to conduct the study (REC REF: 373/2009). Permission was then obtained from the relevant stadium management authorities. Invitations for volunteers to participate in the study were posted on notice boards at UCT's Faculty of Health Sciences campus. Only individuals with normal outer ear appearance, middle ear function and normal hearing thresholds were selected for this study. Written informed consent was obtained from the volunteers once they had been provided with information about the study and agreed to participate.

### Study population

Participants were provided with free match tickets and transportation to and from the stadium. Participants attended soccer matches in Cape Town, between different PSL teams. The first match was in November 2009 at a 40,000-seat capacity stadium (half-full) in Cape Town. There were 19 participants (3 females and 16 males) who attended this match (Group 1) and their ages ranged from 18 to 45 years (median age of 22 years). The second match was in March 2010 at a 52,000-seat capacity stadium (sold out match). Only 10 of the original participants attended this second match. This group (Group 2) comprised 10 males with ages ranging from 19 to 32 years (median age of 20 years).

## Data collection

*Pre-match assessment*

At least 2 hours before the commencement of each match, the participants had an otoscopic examination (to rule out outer ear abnormalities), tympanometry (to ascertain middle ear function), and bilateral pure tone (air and bone conduction) audiometry testing in a sound treated audiometric booth at the following frequencies: 250; 500; 1,000; 2,000; 3,000; 4,000; 6,000 and 8,000 Hz (using GSI 61 2-channel diagnostic audiometer) to rule out peripheral hearing loss.

Integrity of the outer hair cells of the cochlea was assessed bilaterally via distortion product oto-acoustic emissions (DPOAEs) using GSI Audera system. To improve reliability of DPOAE assessment, each DPOAE amplitude measurement was done twice without removing the probe from the ear, and whenever there was some variability, the best response (i.e. response with the highest amplitude) was used. Only responses that were 3 dB or high above the noise floor were used for analysis.

*Match one (Group 1)*

Participants were assigned seats across the stadium stand, from extreme left (facing the soccer pitch) to the extreme right and at different levels from the lowest (closest to the pitch) to the highest level. None of the participants blew the *vuvuzela*.

During the match, one participant who was seated in the middle of the stand wore a personal noise dosimeter (Noise-Pro) with the microphone affixed to his/her shoulder to measure the noise dose at ear level. The dosimeter recording began as soon as the participant entered the stadium and ended as soon as he/she exited the stadium.

In addition, a survey of noise levels was conducted during the match using a Brüel and Kjæar Integrating Sound Level Meter Type 2239A. Equivalent continuous noise level ($L_{Aeq}$) measurements were determined using the A-weighted (dBA) frequency network of the sound level meter. A-weighting is useful for assessing the noise risk to hearing because it de-emphasizes the low and very high frequencies which pose less of a risk to hearing and it also approximates the ears' response to moderate level sounds (NIOSH 1998). Peak noise levels were measured using the C-weighting scale which captures and emphasizes all frequencies.

Therefore, the following recordings were obtained: Peak level ($L_{Cpk}$), which reflected the highest instantaneous sound level detected by the sound level meter; and equivalent continuous noise level ($L_{Aeq}$), which captured the true equivalent sound measured over the recording time (about 2 hours for each match) (NIOSH 1998). Noise dose (*D*), which represents the amount of actual exposure relative to the amount of allowable exposure, and for which a dose of 100 % and above represents noise exposure that is hazardous (NIOSH 1998), was also measured during the match.

*Match two (Group 2)*

This group of 10 participants was divided into two groups of five, with each group having one individual who blew the *vuvuzela*. Two members of each group were seated within 1 m from the *vuvuzela* blower (one on each side of the *vuvuzela* blower), and the other two members of the group were seated more than a meter (at least two rows of seats behind the *vuvuzela* blower) away from the *vuvuzela* blower. For ethical reasons, no one was made to sit immediately in front of the *vuvuzela* blower. The person blowing the *vuvuzela* was requested to blow the *vuvuzela* in a manner that is consistent with the way the *vuvuzela* is usually used during a football match (e.g. when a goal is scored, when their favourite team was “attacking”, etc.).

The person blowing the *vuvuzela* for each sub-group wore a personal noise dosimeter during the match set up as described above. An additional member of the group, who was not blowing the *vuvuzela* and seated at least over 1 m from the *vuvuzela* blower, also wore a personal noise dosimeter to facilitate comparison. The dosimeter recording began when the participants entered the stadium and was ended when they exited the stadium. In addition, noise levels were surveyed as described for Group 1. Finally, 1/3 octave analysis of the *vuvuzela* noise was performed using *Norsonic Nor131 Class 1* sound level meter to determine its spectral characteristics.

*Post-match assessment*

Within an hour after the match, DPOAE measurements were obtained from all participants by the same researcher who conducted the pre-match assessments.

## Data analysis

Peak level ($L_{Cpk}$), continuous equivalent noise level ($L_{Aeq}$), and noise dose were tabulated. DPOAE amplitudes for the pre- and post-match conditions were compared using Wilcoxon Signed Ranks test for repeated measures on a single sample.

## RESULTS

The *vuvuzela* was found to emit broad-spectrum noise comprising frequencies across the range of human hearing (20 Hz–20 kHz) with maximum peaks between 1 and 3 kHz. Figure 1 reflects the results of 1/3 octave analysis (A-preweighted) of the *vuvuzela* noise.

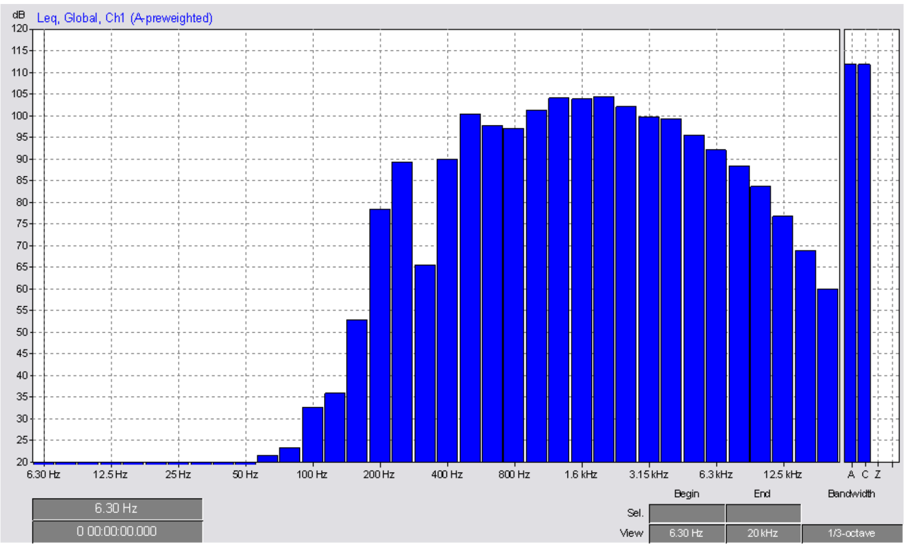


**Figure 1:** Frequency spectrum of *vuvuzela* noise (A-preweighted)

$LC_{pk}$, $LA_{eq}$, noise dose, as well as the duration of exposure to noise (i.e. actual noise exposure) during the two soccer matches are presented in Table 1. Permissible exposure time (SANS 10083:2004), which indicates the duration of noise exposure at a given level that is considered "safe", were also included for comparison.

**Table 1:** Noise levels and percentage dose during the match for three participants

| | **Match 1 *vuvuzela* non-blower** | **Match 2 *vuvuzela* blower** | **Match 2 *vuvuzela* non-blower** |
|---|---|---|---|
| Peak Level (LCpk)) dBC | 115.7 | 134.5 | 132.0 |
| Equivalent noise level (LAeq) dBA | 85.3 | 98.9 | 92.7 |
| Percentage dose (%) | 26 | 684 | 171 |
| Actual time of exposure (minutes) | 125 | 130 | 130 |
| Permissible exposure time | 8 hours | 19 minutes | 76 minutes |

As seen in Table 1, noise levels during Match 1 were lower than those of Match 2. Further, the two participants in Group 2 who blew the *vuvuzela* had higher equivalent noise exposure levels and consequently higher noise dosage than the participants who did not blow the *vuvuzela*. All the participants attending Match 2 were exposed to a noise level of 92.7 dBA for a period that exceeded the permissible duration at that level.

The results of auditory function, as assessed with DPOAEs, are displayed in Figures 2a and 2b. The results displayed in Figures 2a and 2b show the average DPOAE amplitudes for the left ear only (right ear results showed the same pattern). Participants in Group 1 did not demonstrate significant reduction ($p$=0.060) in their OAE amplitude (auditory function) post-exposure to the noise at the match (Figure 2a).

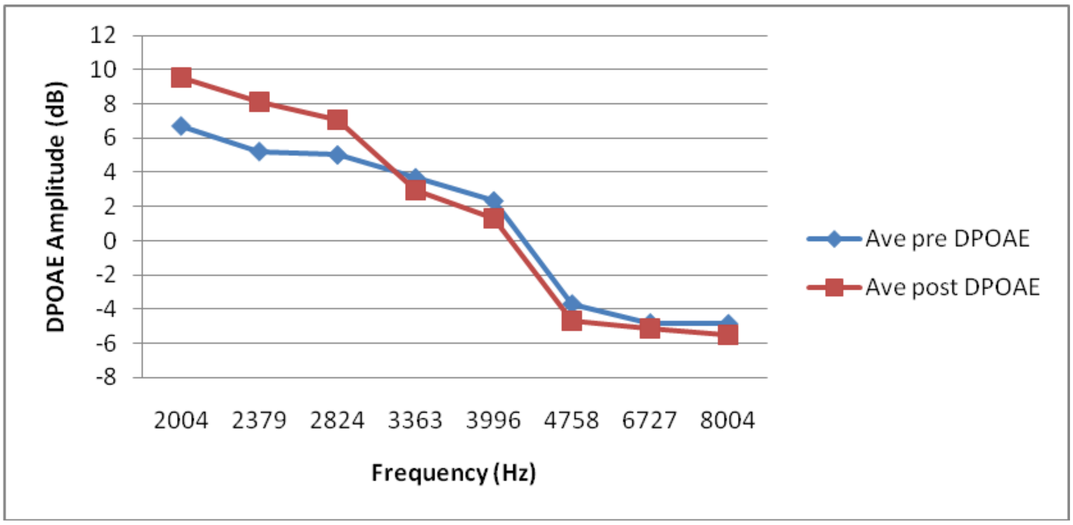


**Figure 2a:** Average left ear pre- and post-match DPOAE amplitude for Group 1 ($n$=19)

Participants in Group 2 exhibited significant ($p$=0.003) reduction in DPOAE amplitude (auditory function) post the match as depicted in Figure 2b. However, when the *vuvuzela* blowers were excluded from this group, the change in DPOAE amplitude post-noise exposure at the match in this group was not significant ($p$=0.117).

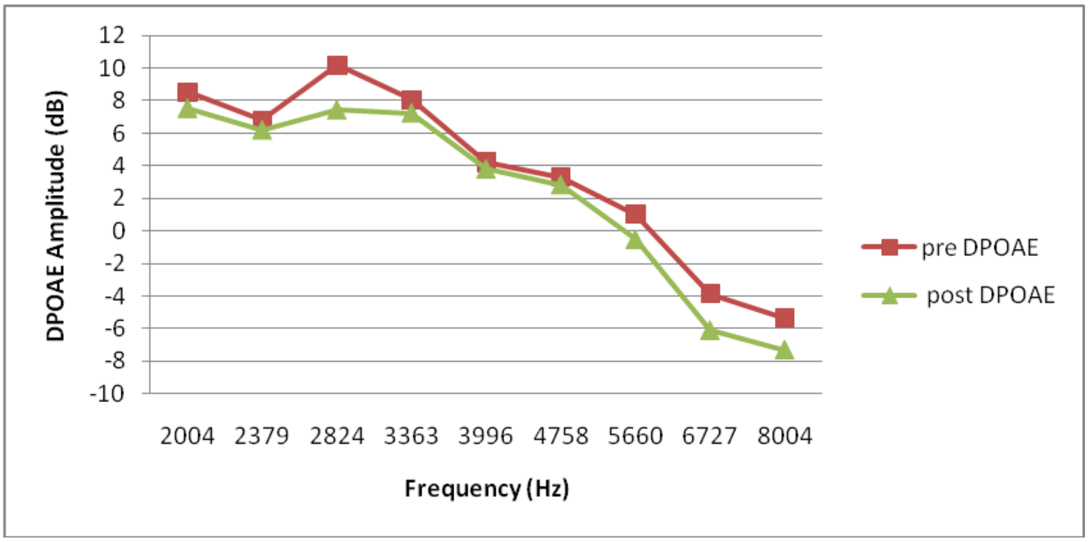


**Figure 2b:** Average left ear pre- and post-match DPOAE amplitude for Group 2 ($n$=10)

The members of Group 2 fell into three categories, viz., *vuvuzela* blowers, within 1m from the *vuvuzela*, and >1 m from the *vuvuzela*. Average changes in DPOAE amplitudes (pre vs. post) for the three groups are displayed in Figure 3.

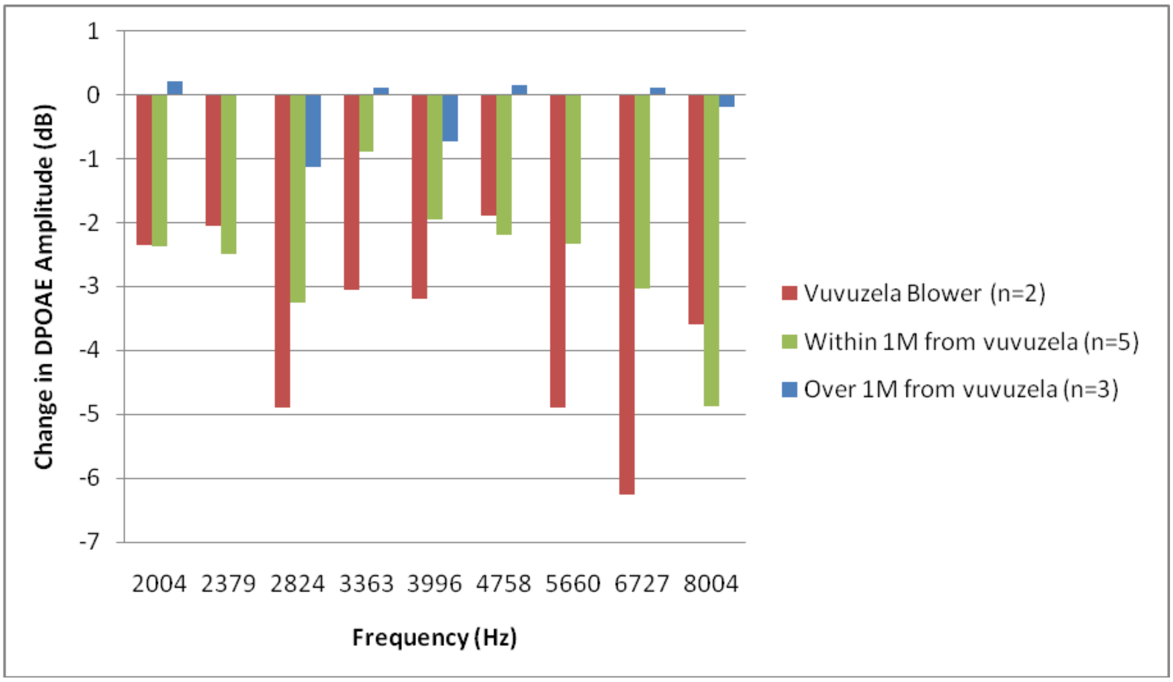


**Figure 3:** Change in left ear DPOAE amplitude as a function of proximity to the *vuvuzela* blower

After the match, *Vuvuzela* blowers had the largest reduction ($p$=0.002) in DPOAE amplitude relative to the other two groups. Participants seated within 1 m of the *vuvuzela* blower displayed the second largest reduction ($p$=0.008). The group seated over 1 m from the *vuvuzela* blower demonstrated a non-significant reduction in DPOAE ($p$=0.238). In general, the largest reduction in DPOAE amplitude occurred in the higher frequencies (5,660–8,004 Hz) when compared to the low frequencies (i.e. frequencies < 5,660 Hz) for all groups of participants.

## DISCUSSION AND CONCLUSION

Exposure to loud noises, whether in an occupational or social setting, has known health effects, including NIHL (Nietzel et al. 2004). This study revealed that the intensity of noise that spectators are exposed to during well-attended ("full house") South African PSL soccer matches is high enough to affect their auditory function as manifested by reduced DPOAE amplitudes after the match. These findings are consistent with those of Swanepoel & Hall III (2010).

The frequency spectrum of the *vuvuzela* noise was found to be similar to that of common industrial noise (i.e. it has a broad spectrum) (Henderson & Hamernik 1986). Due to the acoustic resonant characteristics of the outer ear which tends to amplify sounds in the 2,000–3,000 Hz region (creating a band-pass filter centered at about 3,200 Hz), broad-spectrum noises such as the *vuvuzela* noise typically cause more threshold shift in the 3,000–6,000 Hz region in humans (Royster 1996). This shift is typically observed as a "notch" within this frequency range in the audiograms of individuals with NIHL (McBride & Williams 1995). It was therefore expected that the effect of the noise would be more evident in frequencies higher than the center frequency of the *vuvuzela* noise, with the largest reduction in DPOAE amplitudes in this high frequency region, which was observed in this study.

It was also found that noise exposure is not uniform across matches as evidenced by the substantial differences in noise levels between the two matches. Noise levels for Match 1 were within safe limits. However, the intensity of noise during Match 2 clearly exceeded the SANS 1003:2004 safe exposure level (SANS 2004), confirming the concern that some soccer matches expose spectators to unsafe noise levels. Peak sound pressure levels ($L_C$pk) for both matches were safe for adult ears, but peak sound pressure levels in Match 2 exceeded the recommended limit for children.

In conclusion, the findings of this study confirmed that some PSL matches expose spectators to unsafe noise levels as evidenced by a reduction in DPOAE amplitudes post-match attendance. It was established that the biggest risk factors for overexposure to noise during matches are blowing the *vuvuzela*, close proximity (<1 m) to the *vuvuzela* blower and high spectator turnout at a match.

While the limitations of using DPOAEs to document auditory function is well understood, the use of this test is more sensitive to changes in the auditory function than most available audiometric measures, and hence able to detect a cochlear damage sooner than it can be detected using standard audiologic tests (Marshall et al. 2001).

The authors are also aware of the limitations of using a simple energy-based metric such as A-weighted sounds (dBA) to predict the risk of hearing loss from noise exposure, especially when considering that exposure to the same A-weighted sounds may differ in the potential for causing hearing loss in different individuals.

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# Noise induced hearing loss in the entertainment sector

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## INTRODUCTION

In 2003 the European Union introduced the new noise directive (EC 2003). One of the new requirements in the directive was that all member countries must develop a code of conduct for music and entertainment sector. The European Agency for Safety and Health at Work (2005) has published recommendations for the entertainment sector. In these recommendations it is identified that noise reduction can be obtained by organisational measures, through technical and architectural measures and by using hearing protection. For practice rooms a size of 17 $m^3$ is recommended. Good acoustic design and proper absorption are recommended to reduce the sound levels.

In Finland the code of conduct is intended to be used as a checklist by labour inspectors. It does not provide any practical solutions, how to achieve the goal, but it provides an overall view of the requirements and possibilities. Also the Health and Safety Executive (HSE) provides a similar overall view in their webpage (HSE 2007). The instructions are given by the type of music: concert halls and theatres, amplified music, studios, schools and colleges, pubs and clubs and marching bands. Also the needs of different worker groups, like technicians and freelancers, are identified in a similar way to the Finnish code of conduct.

The Finnish code of conduct divides the workers into 12 groups based on their work tasks and type of employment (Table 1). To make things even worse one worker may belong to several groups. For example many of the music teachers act as part-time musicians.

**Table 1:** Division of the workers based on employment type and character of work and examples of workers belonging to each group

| Employment | Performers | Teachers | Technical staff | Service work |
|---|---|---|---|---|
| Regular | Theatre/opera musicians, actors | Regular teacher | Theatre technical staff | Waiters, safety officers |
| Odd job | Restaurant musician, actors | Part time teacher | Constructors of outdoor event | Waiters, safety officers |
| Own company | Restaurant musician | | Constructors of outdoor event | |

The major problem with the code of conduct is that it does not provide a practical solution. As a consequence there is a confusion in the music and entertainment sector, how to implement the conduct in the field. A second problem was found that research is needed before any implementation can be made. This paper describes the research made in Finland to implement the code of conduct.

## RISK ASSESSMENT

In the music and entertainment sector there are acute and chronic hearing losses. The acute hearing losses are due to special effects (Figure 1). Our survey found in two theatres (Finnish National Opera, Tampereen Työväenteatteri) and in YLE (Finnish Broadcasting Company) over 50 firearms (from machine gun to start pistol), 20 different firecrackers (Figure 1c), and self made bombs (Figure 1a). In addition tanks, canons (Figure 1b), and rockets were available.

a) suicide bomber in Tampere b) Historical canon c) fireworks on scene theatre shooting presentation

**Figure 1:** Examples of impulse noise sources in the entertainment sector

The measured peak levels of these blasts varied from 163 dB (canon, explosions) to 110 dB (firecrackers). The peak levels of the shots in the shooters ears varied from 155 dB to 132 dB depending on the gun and amount of powder. The shooter was not the only exposed one, also the several other actors/musicians could be exposed to peak levels exceeding 140 dB.

The risk of acute acoustic trauma is not known, because the good statistics about it is missing. However, in Helsinki region alone at least 20 cases of acute acoustic traumas have occurred during the past few years.

The exposure of non-performing personnel can be evaluated from the exposure of the broadcast personnel, because they are moving in same places than the non-performing personnel. The highest exposure was found in concerts and sports events. Depending on the location the exposure could be 99 dB(A) in concerts and 93 dB(A) in sport events (Table 2). In addition sound exposure could also exceed the 140 dB peak level in concerts.

**Table 2 :** Noise exposure in various public productions (Järvinen et al. 2004)

| **Production** | **Average (dB(A))** | **Range (dB(A))** |
|---|---|---|
| Concert | 88 | 68-99 |
| Sports | 85 | 69-93 |
| Others | 77 | 69-86 |

The noise exposure of classical musicians was measured among five orchestras in Helsinki region. Most of the musicians were exposed to levels exceeding 90 dB(A) (Toppila et al. 2011; Laitinen et al. 2003). Depending on the instrument the major source of exposure could be personal rehearsals or performances. Typically for percussionists, flautists and some brass players the exposure in personal rehearsal were the most important one.

## EFFECTS OF NOISE

The effect of noise on the hearing of musicians has been debated for a long time. The distribution of hearing losses among classical musicians correspond to that of non-exposed population according to ISO 1999 (1990). By dividing the classical musicians to high and low exposure groups and adjusting to the effects of age, the effect of sound exposure can be shown (Toppila et al. 2011). Although musicians are not susceptible to hearing loss, there is a high prevalence of other hearing symptoms (Laitinen 2005). Temporary ringing in the ears was experienced sometimes by 17%, quite often by 8%, and always by 6% after orchestra rehearsals. The corresponding figures after personal rehearsals were 10%, 5%, and 3%. In GB, temporary ringing in the ears was experienced a bit more in orchestral rehearsals. It was reported that 15% of women, and 18% of men had permanent tinnitus.

Hyperacusis is also common among musicians (Laitinen 2005). Musicians experienced hyperacusis sometimes in 27 per cent of the case, quite often in 13 % of the cases, and always in 3% of the cases. No significant differences existed between the orchestras. The pain musicians felt was described as smart, sharp pain, ripping, grating, jarring pain, sense of pressure, distortion of sounds, humming in the head.

The non-auditorial effects of high music levels were questioned among broadcast personnel (Järvinen et al. 2004). They reported that after high noise exposure events 75% of workers had at least sometimes sleep disturbances, 30% reported vertigo at least sometimes and tinnitus over 50 % of the workers.

## REDUCTION OF EXPOSURE

The Finnish code of conduct recommends that exposure should be reduced by selection of instruments, appropriately designed rehearsal rooms and use of hearing protectors. We have tested the effect of rehearsal rooms and inquired about the use of hearing protectors.

The Code of Conduct (Ministry of Social Affairs and Health 2006) gives requirements for the space needed for the instruments: grand piano and drum set at least 80 $m^3$/person, wind instruments at least 20 $m^3$/person, and other instruments at least 10 $m^3$/person. These numbers are seldomly achieved in real life.

The Code determines the acoustic properties of the facilities by using SFS 5907 (2004), Acoustic classification of spaces in buildings, where the reverberation time for special class rooms is smaller than 1 s, and sound isolation R'w (ISO 140-4, 1998) is bigger than 57 dB. When building new or renovating old facilities, the Code provides class B to be used for music facilities (reverberation time 0.8-0.9 s and the sound isolation R'w bigger than 65 dB). A Class B is a very demanding facility to achieve in sound insulation, especially when renovating old. Class B almost always requires an acoustician to plan it. However, even Class B is not enough when band practise facilities are built.

The effect of good design was tested in a music school in Espoo. No effect to the noise exposure was observed (Koskinen et al. 2010; Table 3). Still the musicians felt that renovations had a positive effect to the work satisfaction.

**Table 3:** Sound exposure measurements before and after renovation

| **Facilities** | ***Instrument*** | **$L_{Aeq}$, before dB(A)** | **$L_{Aeq}$, after dB(A)** |
|---|---|---|---|
| Classroom I | trumpet | 85 | 84 |
| Classroom II | drums | 91 | 93 |
| Classroom II | drums | 87 | 85 |
| Classroom III | French horn | 80 | 84 |
| Classroom IV | accordion | 84 | 75 |
| Classroom IV | accordion | 81 | 71 |

The usage of hearing protectors (HPD) was inquired with a questionnaire in five orchestras in Helsinki region (Laitinen 2005; Figure 2).

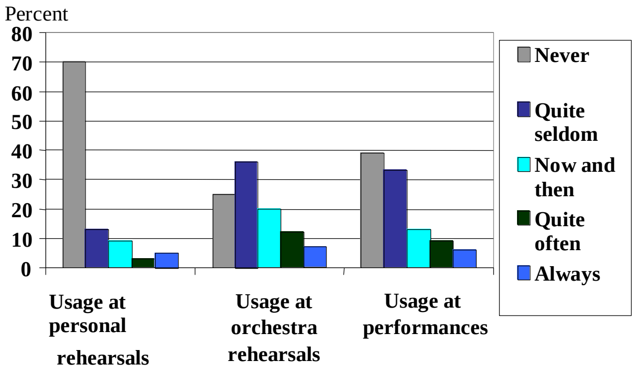


**Figure 2:** Hearing protector usage in work

Usage rate of HPDs was clearly affected by the hearing symptoms (Figure 3). In personal rehearsals, HPDs were used often or always by 2% of musicians without hearing symptoms, and by 12% of musicians with hearing symptoms. The same tendency was shown in orchestra rehearsals (9% versus 22%) and performances (7% versus 20%).

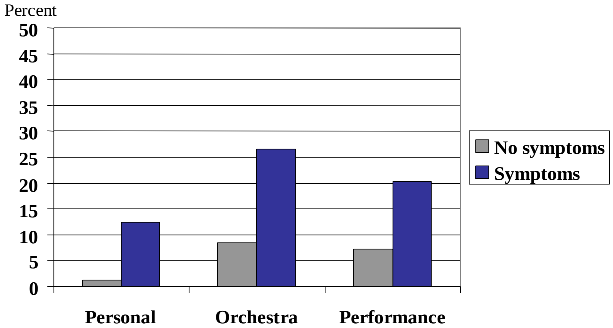


**Figure 3:** Effect of hearing symptoms to the use of HPDs

## DISCUSSION

The Finnish code of conduct has raised confusion in the music and entertainment sector. It is listing many requirements but does not provide any solutions how to fulfill these requirements. It has not taken into consideration the special effects, because the risk was not identified at the time of development. To help the entertainment sector to implement the requirements of code, so far two implementation guides have been developed. The first one is for music schools and the second one is for every one using special effects. The special effect implementation guide is a web-based guide (tehoste.noiseproject.info (in Finnish)). It contains information about the peak levels of different special effect as function of distance and angle, risks and legal requirements. It contains also a section of audience safety, because it was found during the project that poor design can cause high peak levels among audience.

In addition the Finnish National Opera and YLE (Finnish Broadcasting company) have developed their own hearing conservation programs. Taking into account that a hearing conservation program is mandatory, this is a very low number.

The hearing conservation program (Toppila et al, 2001) of the Finnish National Opera was built early in 2001 and updated to take into account the effects of special effects in 2011. It is built of four modules:

- Motivation and training: An information package was made for the use of occupational health care and safety engineers.
- A tutorial how to take in use HPDs in the orchestra. The tutorial gives recommendations, which plugs to choose, how to start to use them gradually and what kind of problems can be expected and how to avoid them.
- In every production, a check to ensure that no unnecessary exposure occurs.
- Possibilities to make changes in rehearsal rooms and design of the stage are checked periodically to reduce the exposure.
- The group rehearsals are timed in such a way that the larger rooms can be used.

Activities are supervised by Hearing Protection committee, composed of the representatives of different artist group and safety engineers.

So far the work has been concentrated on large institutional partners in the music and entertainment sector because they have the resources to develop required actions to protect the hearing of their personnel. The situation becomes more complex with small scale partners in the field. They are lacking resources, knowledge, and they have not the required good will. Simple examples are available from Sweden and Germany, so there is no big need for research. As the researchers have been the most active people in developing methods, it is easy to understand that this kind of implementation has not taken place in Finland.

## CONCLUSIONS

There is a underestimated risk of acute acoustic trauma in the music and entertainment sector. Most of the work has been concentrated on musicians completely forgetting the existence of the personnel involved. Their exposure may be even higher than that of musicians.

## ACKNOWLEDGEMENTS

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# The influence of room acoustic aspects on the noise exposure of symphonic orchestra musicians

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## INTRODUCTION

Musicians in a symphonic orchestra are exposed to the noise of a large number of different sound sources. The noise exposure can vary largely and has many aspects of influence. One group of aspects are musical aspects, like the orchestra size and composition, the musical piece and its interpretation by the conductor and orchestra. The other group of aspects are architectural and room acoustic related which may contribute to a variation in noise exposure, independent of the musical aspects to some extent. On one hand, the size of the stage or orchestra pit may determine the distance between the musicians, which typically influences the direct and early reflected sound paths. Besides that, the room acoustics of the stage and the hall can increase the noise exposure dramatically. In this research, the contribution of stage size and acoustics to the total noise exposure and instrument balance is investigated for 7 concert halls A to G as described by van Luxemburg et al. (2009).

## METHOD

A model for the prediction of sound levels within a symphonic orchestra is used to investigate the influence of the architectural and room acoustical aspects. This model is based on measurements of the sound power $L_w$ and directivity Q of the various instruments, a generic orchestra setup and measured values of the room acoustical parameters sound strength G and the early to late reflection ratio $LQ_{7-40}$ [Braak & van Luxemburg 2008] in different concert halls. The background of the model is described in Wenmaekers et al. (2010, 2011) and is briefly summarized in Figure 1. For every source and receiver pair, the direct sound level $L_{direct}$, early reflected sound level $L_{early;refl}$, late reflected sound level $L_{late;refl}$ and total sound level $L_{total}$ is estimated.

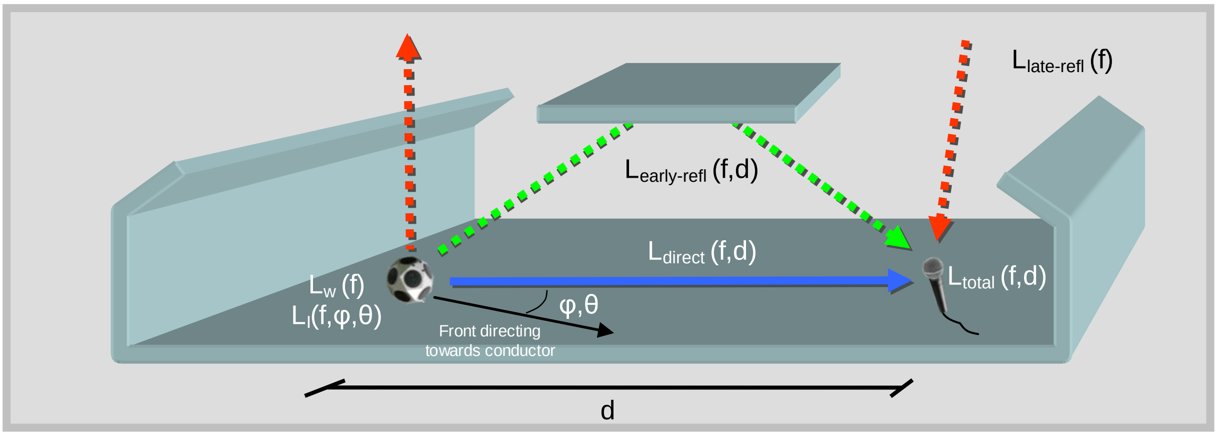


**Figure 1:** Summary of the source – receiver model

The directivity $L_l(f,\varphi,\theta)$ has been determined from anechoic recordings of separate musicians by Pätynen et al. (2008) and Pätynen & Lokki (2010) for 125 Hz to 8000 Hz octave bands averaged over several tones within the instruments range. Besides that, separate instrument recordings were made of different orchestral pieces of music. From the front microphone recordings of the Mahler Symphony no. 1 sample (2:12 min) and Bruckner Symphony no. 8 sample (1:27 min) and a calibrated reference signal, the equivalent sound levels have been determined using Dirac 5. From the directivities and frontal sound levels, the sound power $L_W$ is calculated. Figure 2 shows the A-weighted sound power level per instrument per musical piece. Only large differences occur between the two pieces at the violin sections and horn section. Because of relatively small differences between the two pieces and because the Mahler piece has a percussion part, only Mahler was used for further calculations.

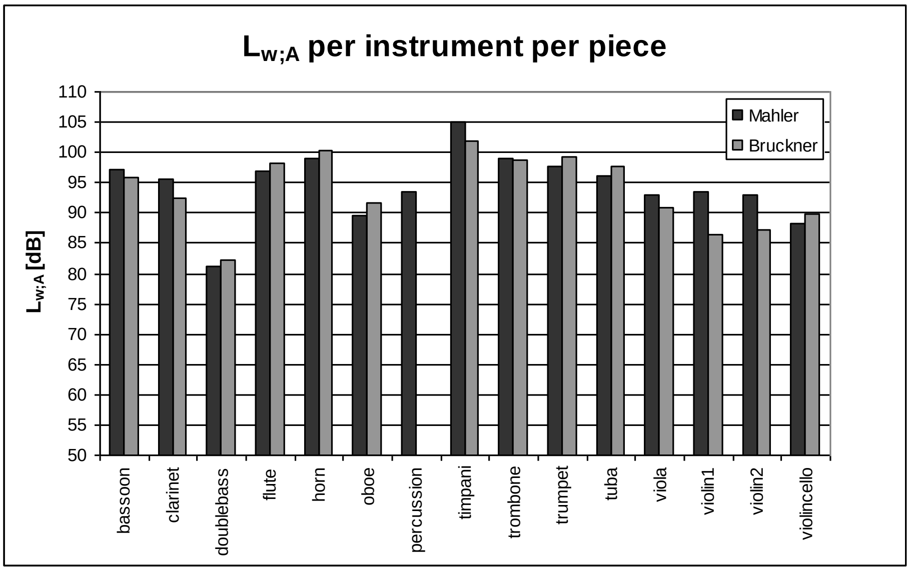


**Figure 2:** Average A-weighted sound power per instrument for different musical pieces

Based on the typical Mahler Symphony 1 orchestration and the typical American orchestra layout (Meyer 2009), an orchestra setup is chosen for the model with all musicians positioned on a rectangular grid, see Figure 3. The receiving musicians investigated further in this paper, are highlighted in red. Musicians 56 to 74 are elevated by 0.3 m and musicians 59 to 79 are elevated by 0.6 m to simulate risers.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | clr | | perc | timp | bso | trb | | | | tba | |
| | 59 | 60 | 61 | 62 | flu | 81 | 82 | 80 | obo | 75 | 76 | 77 | 78 | 79 | |
| hrns | 56 | 57 | 58 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 |
| | 23 | 24 | 25 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | | trp | | |
| vi2 | 17 | 18 | 19 | 20 | 21 | 22 | 30 | 31 | 32 | 33 | vla | | | | |
| | 11 | 12 | 13 | 14 | 15 | 16 | 26 | 27 | 28 | 29 | | cel | 46 | 47 | dbl |
| | 6 | 7 | 8 | 9 | 10 | | | | 38 | 39 | 40 | 41 | 44 | 45 | |
| vi1 | 1 | 2 | 3 | 4 | 5 | | 100 | cond | 34 | 35 | 36 | 37 | 42 | 43 | |

**Figure 3:** Generic orchestra setup for Mahler Symphony 1 (receivers used in paper are marked red)

Strings: 1-14: 1st violin, 15-25: 2nd violin, 26-33: viola, 34-41: violoncello, 42-47: double bass
Woodwinds: 48-51: flute, 52-55: oboe, , 63-66: clarinet, 67-70: bassoon
Brass: 71-74: trumpet, 75-78: trombone, 79: tuba
Separate instruments: 56-62: french horn, 80: timpani, 81-82: percussion

## RESULTS

To study the impact of room acoustics on the noise exposure the contribution of each instrument (82) is calculated for all receiver positions (83). The contribution is subdivided in direct, early, late and total level and calculated for 7 octave bands and for A-weighted spectrum. All calculations have been performed for hall A to hall G (van Luxemburg et al. 2009). In total this yields over 1.5 million calculation results.

In the next paragraphs, only results are presented for hall C with a relatively high amount of early sound and low amount of late sound; and hall F with a relatively low amount of early sound and high amount of late sound. The same mutual distance between musicians is used to simulate average stage size: 1.3 m (width) and 1.6 m (depth), see Table 1. All presented values are A-weighted.

Figure 4 shows the mapping of the exposure level contribution of every individual instrument towards the receivers 8, 41, 63 and 71 per room acoustical parameter for hall C. In the direct sound, the highest contribution is made by the instruments close to the receiver with a large spatial decay rate. The sound power of the instruments seems less distinct, but also shows some influence. In the early reflected sound, less high individual levels occur and the contribution is more spread over the orchestra, clearly showing a stronger contribution of louder instruments. This is even clearer in the late reflected sound, which is only dependant on the sound power of the instruments and the late sound strength of the hall. This results in the same graph for every different receiver. Finally, the total level shows that both distance and sound power are important factors, so even distant instruments can have a large contribution to the total noise level at a receiving position. Also, the highest individual noise levels are produced close to the receiver but the early and late reflected sound may have a large contribution to the noise exposure of the full orchestra.

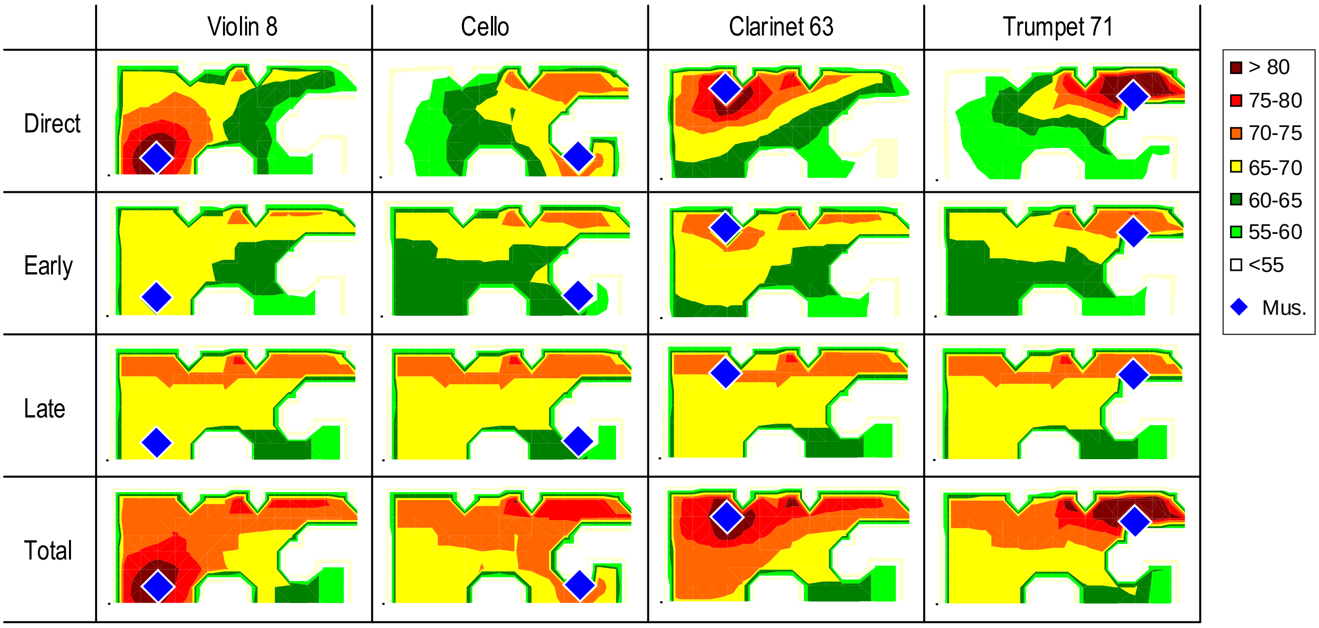


**Figure 4:** Contribution to noise exposure level at single musician from all other musicians (hall C)

Figures 5 to 8 show the balance of the contribution to the noise exposure level of different instrument groups in hall C and hall F at receiver position 8, 41, 63 and 71 respectively. The total contribution of each instrument group on the exposure level is shown for every room acoustical aspect. The presented values show energetically summed levels over all instruments within the same group. Also, the exposure level of the own instrument is presented using dashed bars. The results show that in most cases, the exposure level of closer instrument groups is mainly determined by direct sound transfer while the exposure level of distant instrument groups is mainly determined by late reflected sound. Also, in most cases the noise exposure from the own instrument group is the highest, except for the cello, and the noise exposure from the loudest group is higher than from the own instrument in all cases. In both halls, the late reflected sound is louder than the early reflected sound. However, in hall C, for distant instrument groups, the early reflected sound can be louder than the direct sound, while in hall F, the direct sound is always louder than the early sound.

Figure 9 shows the exposure level of the full orchestra for every instrument group per room acoustical aspect in hall C and hall F. Also, the total exposure level of the own instrument within its group is presented using dashed bars. The presented values show arithmetically average levels over all instruments within the same group. Results show that, for hall F, the noise exposure from early sound is > 5 dBA lower than from late sound, while in hall C, the noise exposure from early sound is < 5 dBA lower than from late sound. Differences between instrument groups can rise up to 5 dBA. It also shows that the contribution of own, direct, early and late sound can be in the same order of magnitude.

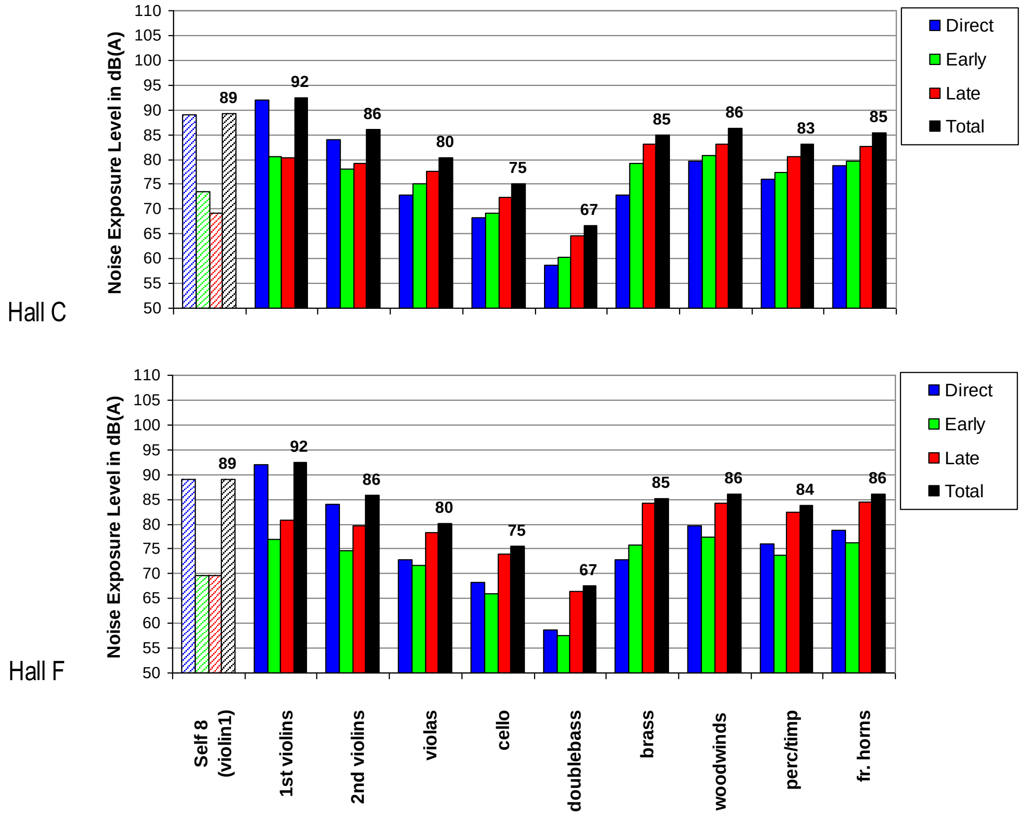


**Figure 5:** Noise exposure balance: violin pos. 8

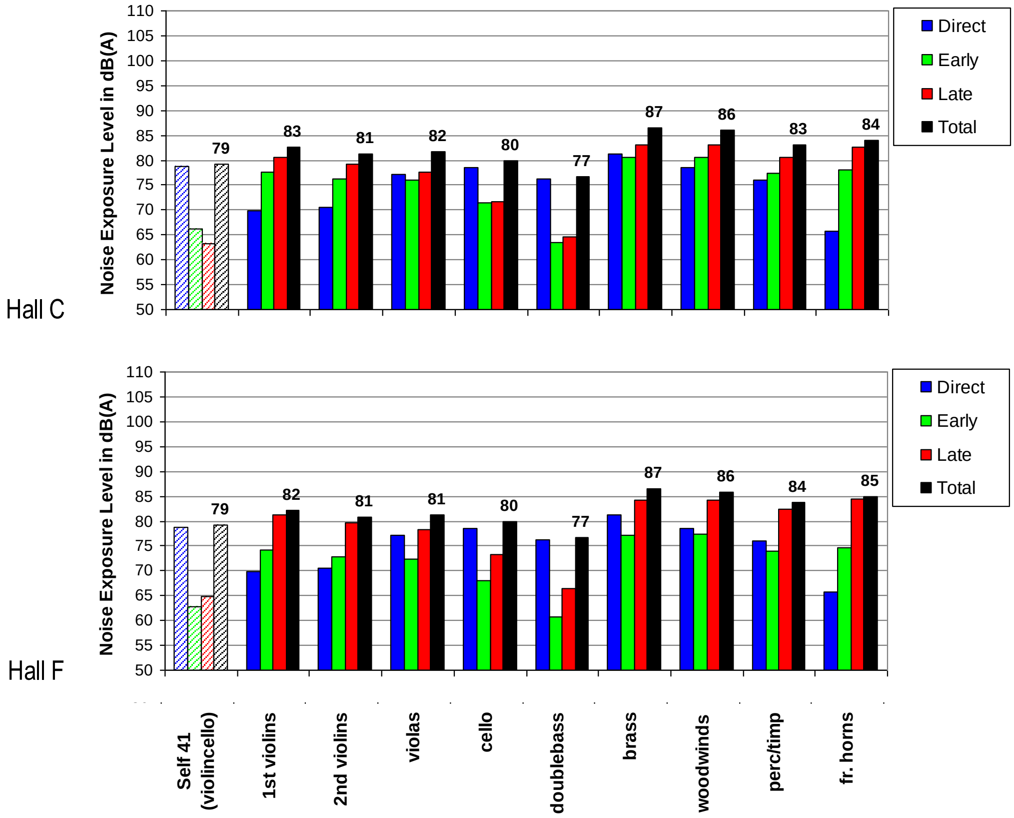


**Figure 6:** Noise exposure balance: cello pos. 41

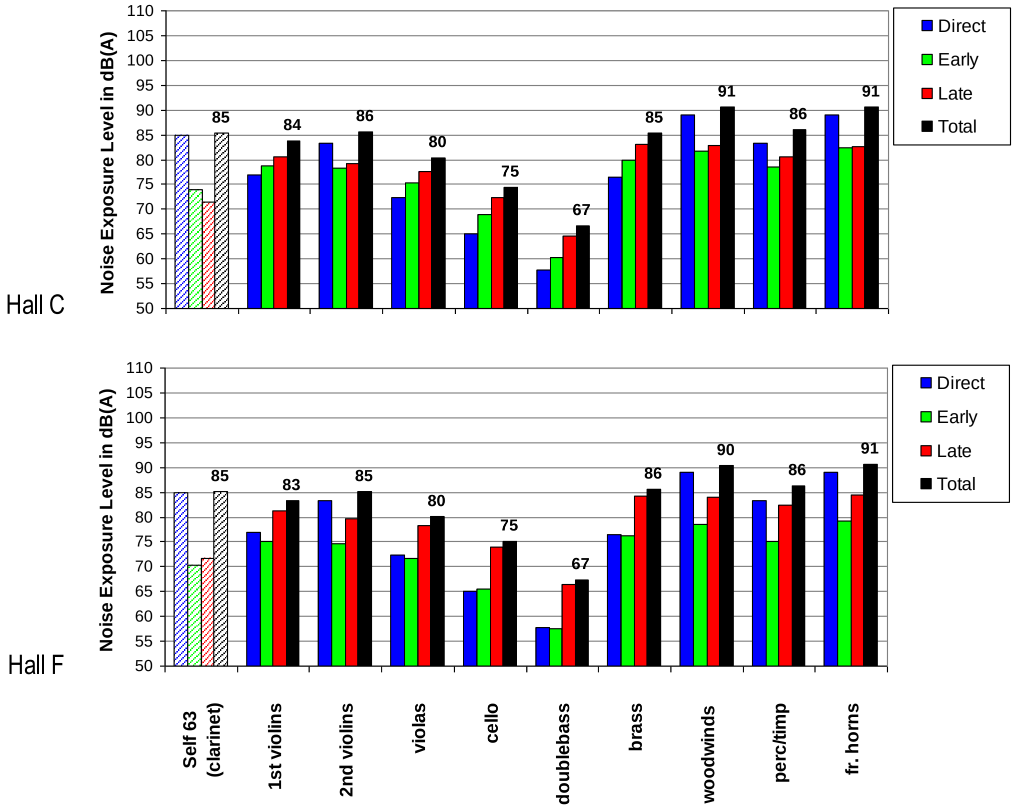


**Figure 7:** Noise exposure balance: clarinet pos. 63

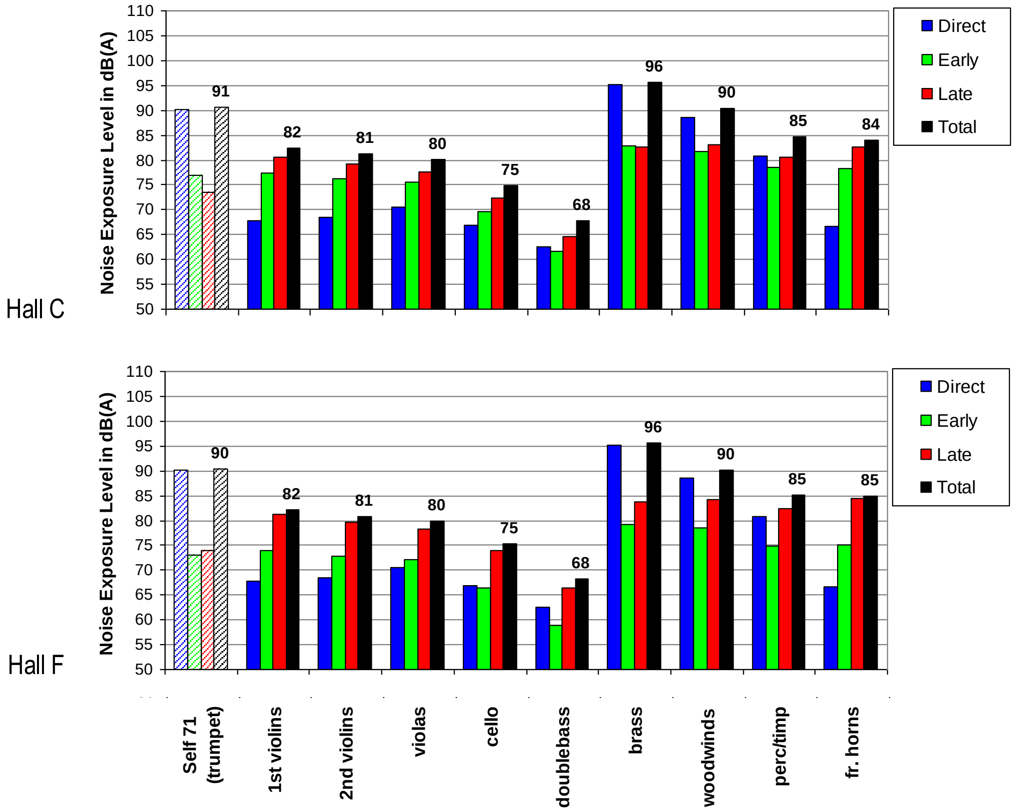


**Figure 8:** Noise exposure balance: trumpet pos. 71

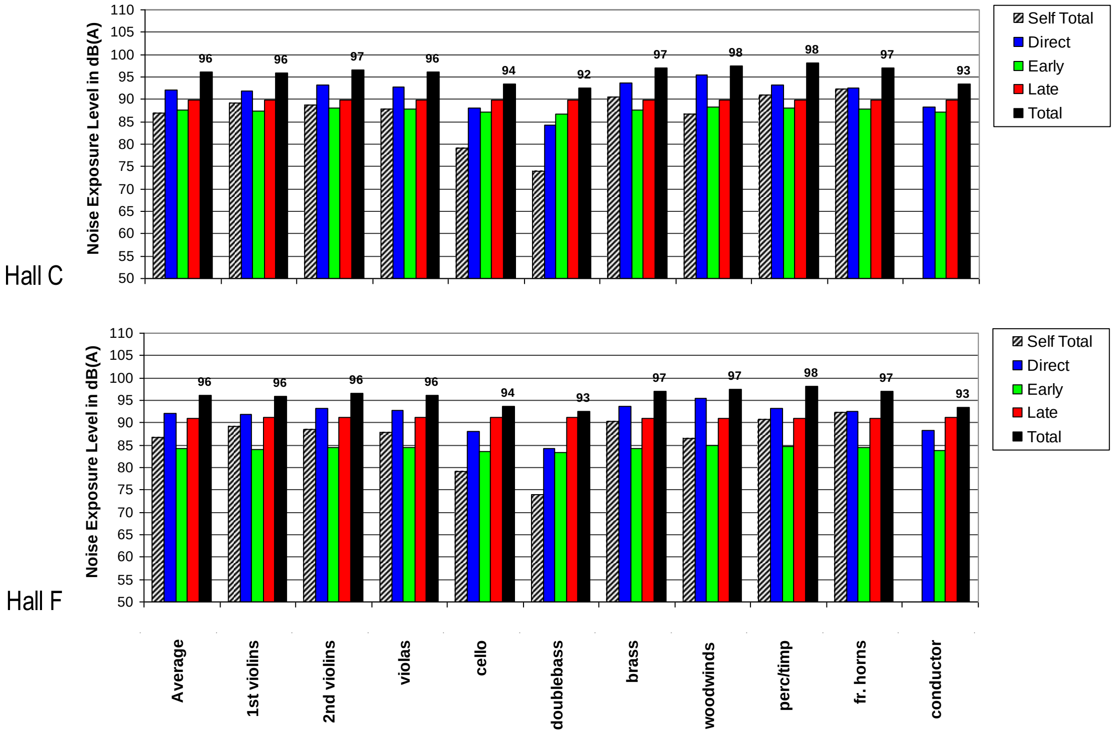


**Figure 9:** Total noise exposure per acoustical aspect and instrument group

The influence of stage size is investigated for the stages of halls B to G. The dimensions and room acoustical properties of the stages are summarized in Table 1. Figure 10a shows the average noise exposure level of all musicians for every concert hall stage for every room acoustical aspect using an equal mutual distance of 1.3 m (width) and 1.6 m (depth). Figure 10b shows the same graph but with the orchestra setup (Figure 3) stretched out over each stage, in accordance with the actual maximum mutual distances, see Table 1. The results show that only the direct exposure level is clearly influenced by the stage size, with differences up to 3 dBA between the different halls. However, the total exposure level is affected by the stage size by less than 1 dBA. Finally, the maximum difference in average total noise exposure level between the different stages when taking into account the stage size is 1.8 dBA.

**Table 1:** Concert hall stage properties

| hall | width (w) | depth (d) | mutual distance w | mutual distance d | $G_{7-40}$*** | $G_{40-inf}$*** | $LQ_{7-40}$*** |
|---|---|---|---|---|---|---|---|
| A* | - | - | - | - | 0.6 | 5.7 | -4.3 |
| B | 16.4 | 11.2 | 1.1 | 1.4 | 2.8 | 8.6 | -4.5 |
| C | 18.0 | 11.5 | 1.2 | 1.4 | 4.2 | 6.1 | -0.4 |
| D | 20.4 | 13.7 | 1.4 | 1.7 | 1.1 | 6.4 | -4.2 |
| E | 17.4 | 11.7 | 1.2 | 1.5 | 0.7 | 5.3 | -3.6 |
| F | 21.6 | 15.0** | 1.4 | 1.9 | -1.0 | 7.8 | -8.2 |
| G | 17.5 | 12.6 | 1.2 | 1.6 | 0.9 | 7.0 | -5.1 |
| Average | 18.6 | 12.6 | 1.3 | 1.6 | 1.3 | 6.7 | -4.3 |

* Stage A is not a rectangular stage, so it cannot be defined by width and depth. Therefore it has not been used.
** The real depth of the stage in hall E is 17.5 m, however it assumed that a maximum of 15 m is used by the orchestra.
*** Average of 500 Hz and 1000 Hz averaged over 36 source-receiver combinations per stage (Wenmaekers et al. 2010)

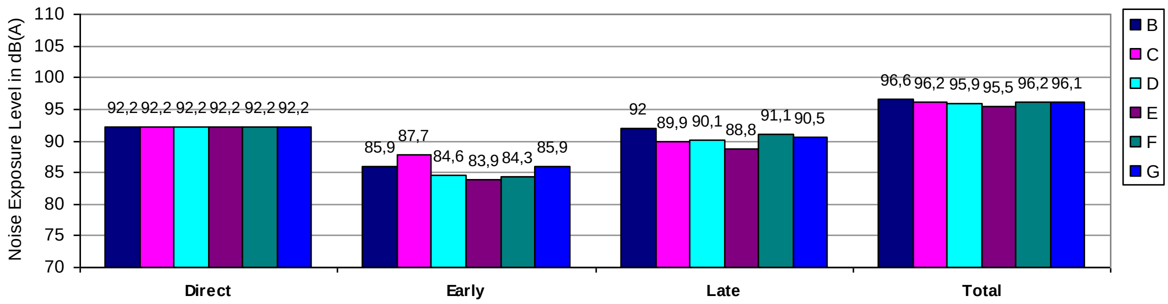


**Figure 10a:** Musician average noise exposure per acoustical aspect per hall – average stage size

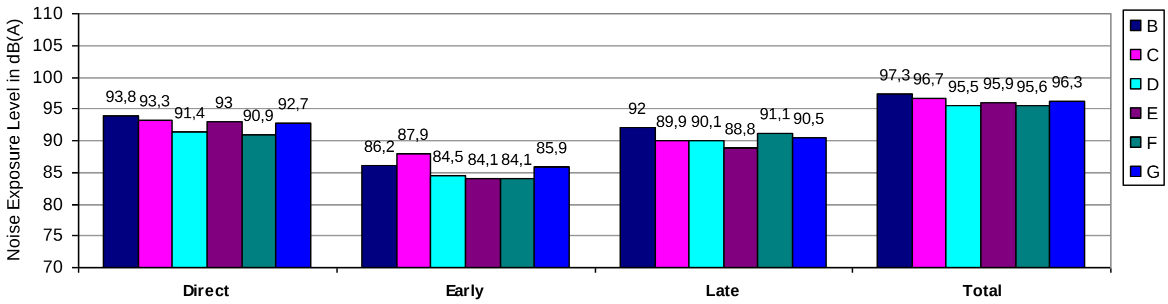


**Figure 10b:** Musician average exposure per acoustical aspect per hall – actual stage size

## FURTHER RESEARCH

The presented work is a result of a feasibility study for developing a model to estimate the sound levels within an orchestra. It is shown that the model has much potential for studying the influence of architectural and acoustical aspects on the noise exposure of musicians in a symphonic orchestra. In future, it would be interesting to use the model to study the impact of screens between musicians and different orchestra setups on the noise exposure. Also, more different types of stage environments could be analysed, like orchestra pits and theatre stages. It is shown that the model can give valuable insight in the sound level balance of different instruments in a symphonic orchestra. The results could also be used to study the effect of orchestra setup and room acoustics on ensemble playing (Gade 2010).

The impact of some assumptions and simplifications needs further investigation. The directivity of the instruments and attenuation by the orchestra is not taken into account in the measured room acoustical parameters which may result in an overestimation of the early reflected sound (Dammerud 2010). Also, the time transition point between early and late reflected sound of 40 ms needs further investigation (Wenmaekers et al. 2010). Furthermore, an estimation is made of the own instruments sound level by using a small source-receiver distance using the far field sound power and directivity, while in reality the listener is in the instruments near field.

## ACKNOWLEDGEMENTS

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# Hearing function in workers engaged in industry: Georgian material

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## INTRODUCTION

By the prevalence rate noise-induced hearing loss keeps the second place in the list of cochlear pathologies, the first position being occupied by the age-related impairments (Cruickchanks et al. 2010; Helfer et al. 2010). Disturbing effects of high-intensity sounds on health, in general, on inner ear, in particular, have been investigated for a long time. The influence of noise on hearing function in industrial workers was in particular the topic of some special debates (Eleftherioou 2002; Meyer et al. 2002). Noise-induced hearing impairment seems to be the major avoidable auditory disorder (Dobie 1995). Systematic audiometrcal inspection appears thus essential for detection of incipient stages of the pathology. If revealing any dysfunction hints, protective technical procedures have to apply or to reinforce the existing items while specific medical manoeuvres have to accomplish aiming the rehabilitation of happened distortion and/or prevention of its further progressing. Background and regular dynamic audiometric testing should be carried out particularly on individuals being regularly engaged in noisy job affairs (McBride 2004).

The aim of the present study was the tracing of the consequences of systematic industrial noise exposures on hearing function in workers involved in construction of transcaucasian oil-pipe line in Georgia. The distinct purpose of performed investigations was the evaluation of hearing thresholds in industry workers within the wide range, including 10 kHz and 12 kHz frequencies, that being dissimilar from the routine audiometrical examinations where the high-frequency border is conventionally limited by 8 kHz. The referent control probes were in parallel fulfilled on co-workers of neighbor humanitarian organizations.

## METHODS

The test group covered 157 workers engaged in transcaucasian oil-pipe line manufacturing jobs. The control group was represented by 115 employees of non-industrial, mostly of educational local institutions. Either the test and control sample was divided into five consecutive decade age subgroups: 20-29, 30-39, 40-49, 50-59, and 60-69 years. The transcaucasian oil-pipe line is relatively a new development. The job noise influences in most test subjects was thus rather limited in time and generally covered months up to the pair of years. In separate individuals only, the service term approximated to 3, 4, 5 years.

Individuals of both test and control groups have been inspected at first otoscopically and tympanometrically and all were proved to own normal outer- and middle-ears. None of the subjects of the control group reported job-related or any other type of high-intensity sound-exposure incident in the past while all individuals of both groups rejected potentially confounding any other hearing disturbing affair: application of ototoxic drugs, hormonal disorders, bilirubinaemia, etc. Hearing acuity has been assessed via the tonal audiometer (ITERA, Madsen) in a sound-proof room. Air- and bone-conduction thresholds were estimated in both ears consecutively within the extended frequency band, 0.125-12 kHz. The audiometric data in individuals of different age subgroups of test and control samples were compared statistically via the Student's *t* test.

## RESULTS

At lowest frequencies, 0.125-0.5 kHz, hearing thresholds in test and control groups were identical proving no low-frequency perception alterations under high-intensity noisy environment influences. The thresholds appeared rather similar at 1-3-kHz frequencies also although a slight while dubious trend to the higher hearing thresholds in the test vs. control group was likely traced with respect to. At higher frequencies, 4, 6, 8, 10, and 12 kHz, on the other hand, the hearing thresholds in the worker group noticeably and systematically exceeded those in the control group. The 4-12-kHz frequency band appeared thus particularly sensitive to high-intensity industrial noise effects. To focus the attention of readers just to the reliable group dissimilarities, in both offered illustrations (Figures 1 and 2) the results of 0.125-0.5-kHz frequencies are omitted totally while those of questionable 1-3-kHz and indisputable 4-12-kHz frequencies are represented only.

The hearing threshold differences between the test and control groups by the general pattern appeared rather similar in three initial age subgroups, 20-29, 30-39, and 40-49 years (Figures 1 and 2). In all of them the differences systematically accentuated from the lower to the higher frequencies. The greatest gaps between were correspondingly seen at utmost components of the applied frequency band, 12 and 10 kHz. At 12-kHz frequency, in particular, the test vs. control threshold differences in the age subgroups of 20-29, 30-39, and 40-49 years amounted on the mean to 17.9, 10.7, and 10.6 dB, respectively, while at 10-kHz frequency to 7.3, 9.1, 13.6 dB, respectively. At 12-kHz frequency the group differences were statistically significant in all three considered age subgroups ($p<0.01$, $<0.01$, and $<0.005$, respectively). At 10-kHz frequency, on the other hand, the group difference appeared significant ($p<0.01$) in the age subgroup of 40-49 years only. Those in the age subgroups of 20-29 and 30-39 years remained non-significant although also seemed reliable. Generally, taking into account the common audiogram patterns in the test and control individuals, within the band of 4-12-kHz frequencies the group dissociations looked rather systematic while the absence of statistically significant outputs could be attributed to the limited number of observations in separate age subgroups.

In the age subgroup of 50-59 years, as in three preceding subgroups, hearing thresholds in the test sample at high boarder frequencies, 12 and 10 kHz, exceeded those in the control sample. The extents of differences were however statistically non-significant and qualitatively much smaller, amounting on the mean to 5.6 and 3.9 dB, respectively. At preceding components of the noise-sensitive frequency band, 8, 6, and 4 kHz, on the other hand, threshold deviations between the test and control individuals were preserved both in sign as well as in degrees. The most noticeable difference between appeared at 4-kHz frequency. It amounted on the mean to 11.5 dB and reached the statistically significant level ($p<0.05$). At two remainder components of the critical frequency band, 8 and 6 kHz, the group differences were somewhat smaller, 9.0 and 8.9 dB, respectively, and appeared reliable although failed to reach the statistically significant level.

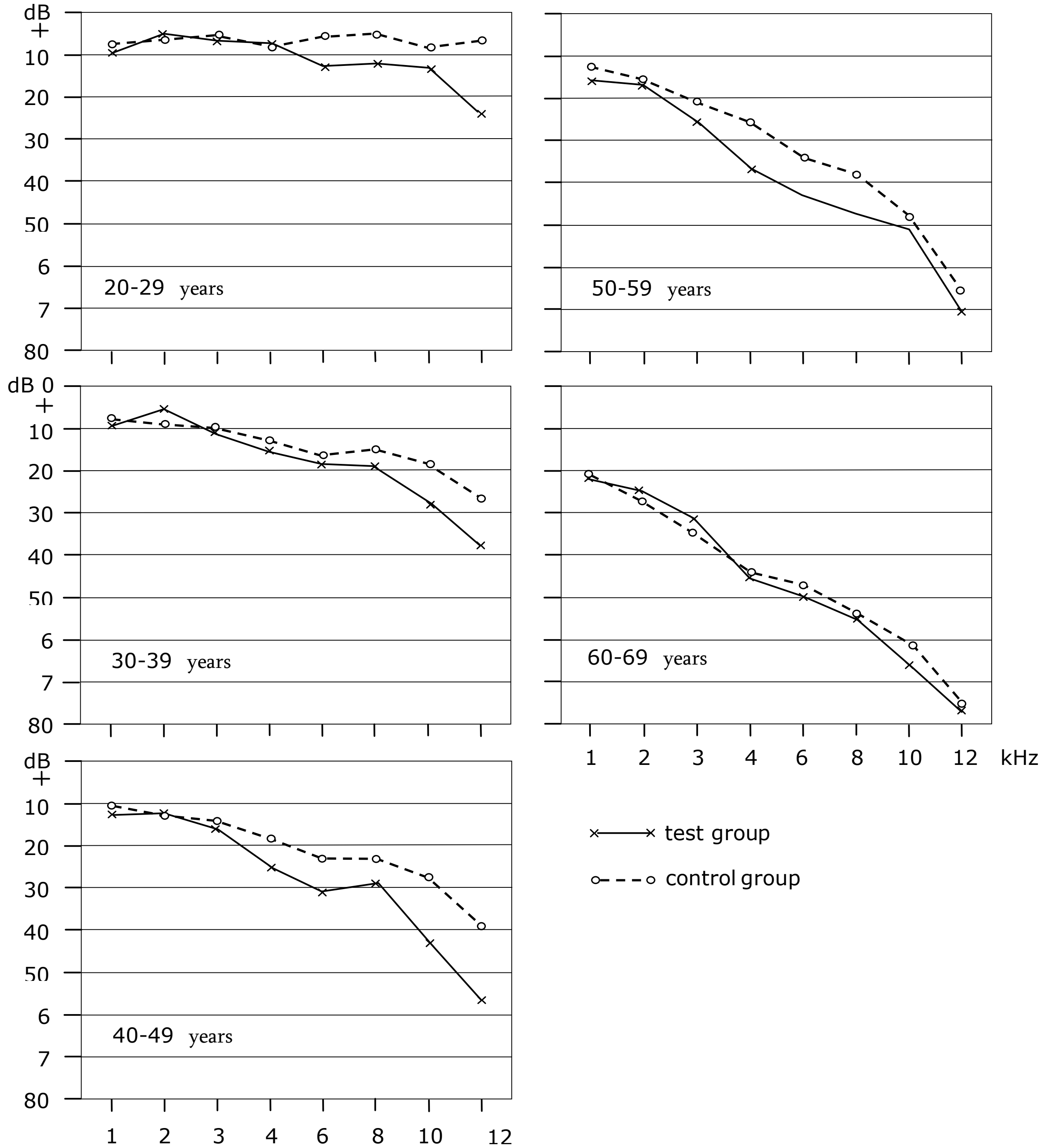


**Figure 1:** Mean hearing thresholds (dB) in individuals of test and control groups of different age subgroups (years) at 1-12 kHz frequencies

In the utmost age subgroup, 60-69 years, hearing threshold differences between the test and control samples were minute, irregular, and statistically non-significant for all inspected frequency components (Figures 1 and 2). At all constituents of the noise-sensitive frequency band, 12, 10, 8, 6, and 4 kHz, the trends towards greater hearing thresholds in the test vs. control individuals were nevertheless preserved. The mean differences between were though petty, only 2.2, 4.3, 1.4, 2.5, and 0.5 dB, respectively, and statistically far not significant.

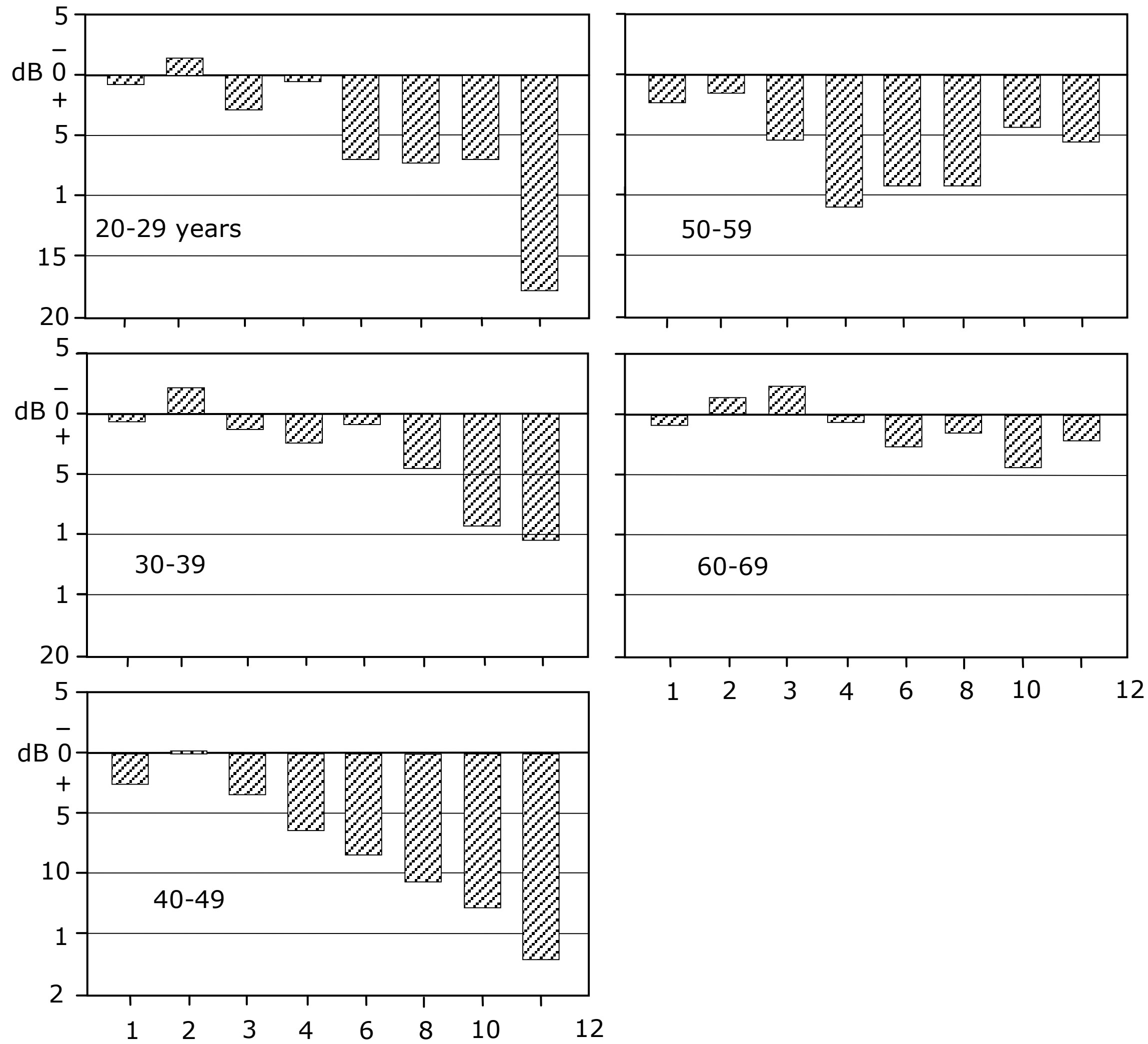


**Figure 2:** Differences between mean hearing thresholds (dB) in individuals of test (columns) and control (0 dB) groups of different age subgroups (years) at 1-12 kHz frequencies

The data of accomplished investigations have demonstrated that in individuals of young and elderly ages, 20-29, 30-39, and 40-49 years, high-intensity job-related noises preferentially affect the perception of sounds of 12- and 10-kHz frequencies. The sensations of other constituents of the high-frequency band, 8, 6, and 4 kHz, are also underwent impaired influences although consecutively of lesser and lesser degrees. The perception qualities of still lower frequencies, 3 kHz and less, are hardly subjected to any regular industrial noise effects. The sensitivity of the 12-4-kHz frequency band to the high-intensity industrial noise expositions appears rather similar in subjects up to 50 years of age.

In subjects of the next age decade, 50-59 years, age-related changes are significantly advanced in cochlea resulting in noticeable increments in sensation thresholds, particularly at utmost audiometrical frequencies, 12 and 10 kHz (Sharashenidze et al. 2007). Due to hearing losses over the certain critical level, the environmental noise fails to exert additional disturbing influences on perception of sounds just of 12- and 10-kHz frequencies. With regard to the preceding constituents of the noise-sensitive frequency band, 8, 6, and 4 kHz, on the contrary, the extents of age-related threshold alterations still remain under the critical level. Due to the noise influences therefore the hearing thresholds at 8-4-kHz frequencies continuo to increase regularly. Generally, thus, in individuals of 50-59 years of age the noise-sensitive frequency field is narrowed while is restricted to the inferior part of the intrinsic band: 8-4 kHz instead of 12-4 kHz.

In the oldest age subgroup inspected, 60-69 years, due to further age-related alterations in cochlea, hearing sensation capacities are additionally reduced within the total noise-sensitive frequency band, 12-4 kHz. Just due to the significant hearing threshold increments, job-related noises stop to exert further harmful influences on cochlear receptors. Hearing threshold differences between workers and non-workers are minimized therefore and become unreliable.

Because of high-frequency hearing perception qualities, individuals of younger ages, up to 50 years, are more subjected thus to the job-related noise influences. In individuals of older ages, more than 50 years, due to critical age-related increments in auditory thresholds, job-related noises gradually stop to affect additionally the hearing sensitivity. Correspondingly, the noise influences become more restricted in width and limited in degree. Moreover, in individuals over 60 years of age the job-noise effects are actually eliminated totally.

## CONCLUSIONS

Hearing impairment consequences of regular noise exposures in workers engaged in industrial jobs concern selectively high sound frequencies, 12-4 kHz. Noise-induced hearing deterioration particularly invades 12- and 10-kHz frequencies.

Systematic audiometrical inspection of industrial workers within the extended band, covering 10- and 12-kHz frequencies, serves to detect the starting hearing disorder hints even. The negative trends should be followed by organization of complex of reliable technical and/or medical services aiming to neutralize harmful noise influences and to block or rehabilitate already happened sensorineural dysfunctions.

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**The final paper was not available at deadline.**

# Four-chamber Cochlea box model: Establishing acoustic comfort, illustrating injury and towards therapy

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ABSTRACT

The unrolled cochlea is modeled using the finite-element software ANSYS13, with four inner chambers representing the Scala Vestibuli contiguous with the Scala Tympani thru a rounded helicotrema, the Scala Media, the inner and the outer hair cells. The tectorial membrane is represented as a plate in contact with the hair cells. An improvement to previously presented results is the inclusion of a tapered helicotrema. Various geometries are compared, i.e. with straight sides and with tapered sides, and see the differences in the frequency response of the models.

Applying real values for material properties and the human hearing range and using characteristic frequency at certain nodes inside the Scala Media, the tapered model is calibrated to establish the reference comfort. Hearing injury is regarded by subjecting nodes to increasing sound pressure levels until the frequency response disappears. This is done at the same time monitoring the change in electrical potential in the inner and outer hair cell regions. The potential change between the normal and the injured conditions is inputted to the Gibbs energy equation for the ATP-ADPase glycolysis to identify a possible route to remedy.

**The final paper was not available at deadline.**

## Noise exposure and hyperacusis

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ABSTRACT

Hyperacusis is reduced tolerance for sounds which is often seen as a precursor for tinnitus. Reduced uncomfortable loudness levels are characteristic of hyperacusis. It has been thought that occupational noise exposure does not usually result in hyperacusis but tinnitus has been reported as ranging in various studies from 5.9 % to 87.5 % of noise exposed workers. The notion of noise sensitivity and annoyance in relation to noise has been studied extensively but the extent of hyperacusis in noise sensitive subjects has not been examined. This paper will examine the relationship between noise and stress behavior in order to elucidate further stress induced auditory hyper-sensitivity. Possible mechanisms of noise-induced hyperacusis will be considered.

# Are occupational noise-exposure levels declining?

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## INTRODUCTION

In industrialized countries chemical exposures are generally lower today than they were years or decades ago (Symanski et al. 1998), but it is unclear if this also is the case for noise exposure. In the United States noise exposure levels decreased in the 1980s and 1990s according to the Occupational Safety and Health Administration but data were collected to document consultation interventions and not for surveillance purposes (Middendorf 2004). In Europe no longitudinal surveillance data are available for noise levels but 30 % of workers report that they at least a quarter of their working time are exposed to noise so loud that they have to raise their voice and this proportion was unchanged from 2000 to 2010 (European Foundation for the Improvement of Living and Working Conditions, 2010). In Denmark 2001-2002 a mean noise level of 83.7 dBA and a two-fold increased risk of hearing handicap was recorded in a random sample of companies from manufacturing industries, construction, and children day care (Kock et al. 2004; Rubak et al. 2006). This paper reports an 8-year follow up of noise levels in this Danish population.

## METHODS

In 2001-2002, we recruited companies at random from the manufacturing industries and construction trades in Denmark with the highest reporting of cases of occupational hearing loss, children day care units, and as a reference financial intermediation, in all 84 companies. In 2001-2010, 39 of the same companies agreed to participate, as well as 37 new companies recruited according to a similar procedure as in 2001-2002. From a total of 121 companies, 1,218 workers participated (743 in 2001-2002 and 475 in 2009-10). Company participation was 60.6 % in 2001-2002 and 24.3 % in 2009-2010. Participating workers recorded full-shift noise exposure levels with portable dosimeters (Bruel & Kjær model 4443). We estimated the mean full-shift noise exposure levels and the proportion workers exposed above 85 dBA in 2001-2002 and 2009-2010, and the changes during the 8-year period in linear and logistic regression models adjusted for trade and total number of employees within a company. In separate analyses we included only companies participating at both rounds.

## RESULTS

The overall average full-shift noise levels were 82.5 dBA in 2001-2002 and 81.5 dBA in 2009-2010 (Figure 1). In the exposed trades (manufacturing industries, construction and children day care) these values were 83.7 dBA and 82.8 dBA, respectively and in finance 69.7 dBA and 70.5 dBA, respectively (Table 1). During the 8-year follow up the adjusted noise level decreased by 0.9 dBA (95% CI 0.3-1.6 dBA) in the exposed trades (Table 1). This corresponds with an 0.1 dBA annual decline. If we restricted the analysis to exposed companies participating at both rounds the adjusted 8-year decline was 1.2 dBA (95% CI 0.3-2.2 dBA). The proportion workers exposed > 85 dBA decreased significantly from 38.4 % to 31.7 % (adjusted odds ratio 0.72, 95% CI 0.55-0.95) (Table 2). Companies with above mean noise exposure levels in 2001-2002 (> 82.5 dBA) had a lower participation rate in 2009-2010 than companies with below mean noise levels in 2001-2002 (odds ratio 0.62, 95% CI 0.26-1.49).

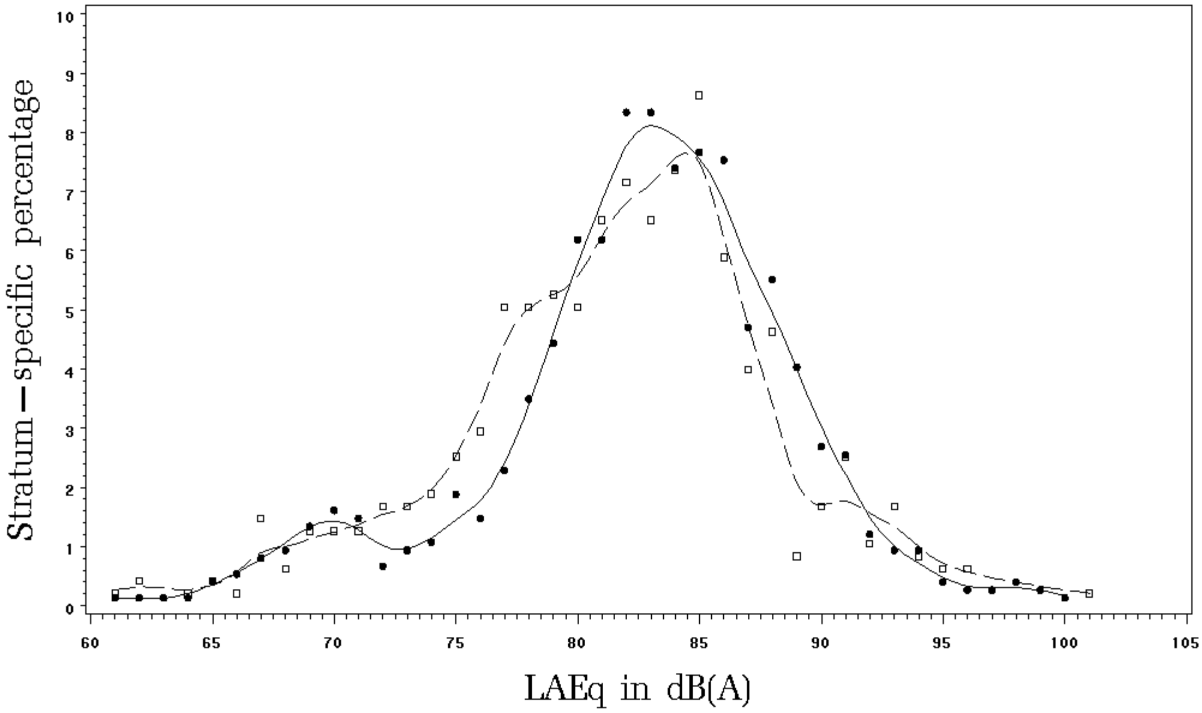


**Figure 1:** The distribution of mean, full shift noise levels ($L_{AEq}$) during 2001-2002 (solid line) and 2009-2010 (dotted line). Results from 1218 measurements of a sample of companies from manufacturing industries, construction, children day care and finance intermediation (reference)

CONCLUSION

During the 8-year period 2001-2002 to 2009-2010 the noise exposure levels in this random sample of companies from manufacturing industries, construction and children day care decreased by about 0.1 dBA annually. The proportion workers exposed above the threshold limit value of 85 dBA declined from 2001-2002 to 2009-2010 but was still substantial.

As far as we are aware this is the first time a systematic, longitudinal surveillance of noise exposure levels has been conducted in a national sample of companies. The low participation rate was a limitation and we may have under (or over) estimated the true noise levels in the industries at large. Participation rate at follow up in 2009-2010 was even lower for companies with high noise levels during the first round in 2001-2002 and this may explain at least some of the decrease seen. However, when we restricted analyses to companies participating at both rounds we observed a stronger effect and this does not suggest differential loss from follow up. Decline in production (due to the financial crisis) may explain the findings but we adjusted for change in number of employees, a measure that is expected to reflect production activity. In 2003 intensified requirements regarding the exposure of workers to noise were enacted by the European Parliament and enforced in Denmark by 2006 (European Union 2003). This study indicates that such policy changes may have had significant impact on noise levels and thus the working conditions but can off course not exclude the possible impact of other societal or technical factors.

**Table 1:** Change in mean, full-shift noise levels ($L_{Aeq}$) from 2000-2001 to 2009-2010 within manufacture, construction, and day care and a reference of finance intermediation. Results obtained from a random sample of 1,218 workers of 121 companies

| | 2001-2002 | | | 2009-2010 | | | Change from 2001-2002 to 2009-2010§ | |
|---|---|---|---|---|---|---|---|---|
| Companies studied | No. of workers | Crude mean 95% CI | Adjusted mean* 95% CI | No. of Workers | Crude mean 95% CI | Adjusted mean 95%CI* | Crude mean 95% CI | Adjusted mean* 95% CI |
| Manufacture, construction and day care | | | | | | | | |
| All companies | 682 | 83.7 83.3-84.1 | 81.4 80.4-82.4 | 423 | 82.8 81.8-83.9 | 80.5 78.8-82.1 | 0.8 0.2-1.5 | 0.9 0.3-1.6 |
| Companies participating at both rounds | 304 | 83.3 82.7-83.9 | 80.5 79.0-81.9 | 202 | 81.8 80.3-83.4 | 79.3 76.9-81.6 | 1.5 0.5-2.4 | 1.2 0.3-2.2 |
| Finance intermediation | 61 | 69.7 68.5-70.8 | 69.4 68.1-70.7 | 52 | 70.5 67.6-73.4 | 69.8 66.9-73.2 | -0.9 -2.6-0.9 | -0.4 -2.5-1.7 |
| All participating companies | 743 | 82.5 82.1-83.0 | 81.2 80.2-82.1 | 475 | 81.5 80.3-82.7 | 80.4 78.8-81.9 | 1.0 0.3 - 1.8 | 0.8 0.2-1.4 |

*Adjusted means from linear regression models that included calendar year (2 levels), industry (12 levels), and number of employees (5 levels). The presented means are computed for printing industry with 30 employees except for analyses restricted to finance .
§A change < 0 denotes increasing noise level

**Table 2:** Change in number of workers exposed to full-shift noise levels ($L_{AEq}$) ≥ 85 dBA from 2001-2002 to 2009-2010 within manufacture, construction, and day care and a reference of finance intermediation. Results obtained from a random sample of 1,218 workers of 121 companies

| | 2001-2002 | | | 2009-2010 | | | Change 2001-2002 to 2009-2010 | |
|---|---|---|---|---|---|---|---|---|
| Companies studied | No. of workers | No. exposed ≥85dBA | Proportion exposed ≥85dBA | No. of workers | No. exposed ≥85dBA | Proportion exposed ≥85dBA | Crude OR 95% CI | Adjusted OR 95% CI |
| Manufacture, construction and day care | | | | | | | | |
| All companies | 682 | 262 | 38.4 % | 423 | 134 | 31.7 % | 0.74 0.58-0.96 | 0.72 0.55-0.95 |
| Companies participating at both rounds | 304 | 109 | 35.9 % | 202 | 51 | 25.3 % | 0.60 0.41-0.90 | 0.61 0.40-0.94 |
| All participating companies | 743 | 262 | 35.3 % | 475 | 134 | 28.2 % | 0.72 0.56-0.93 | 0.72 0.55-0.95 |

*Adjusted odds ratios from logistic regression models that included calendar year (2 levels), industry (12 levels), and number of employees (5 levels)

To conclude, this study suggests that noise exposure levels have declined with about 0.1 dBA annually during the beginning of this millennium and indicates that recent initiatives to reduce noise exposure levels have been successful.

## ACKNOWLEDGEMENTS

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# The audience is influenced by the loud sound in the open-air stage concert in the campus festival

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## INTRODUCTION

Our campus festival is promoted by the students of the festival society at Shibaura Institute of Technology for 3 days every year. It is held the event and the booth where participant sells frankfurts, beers and etc. The students build the open-air stage in the festival, and then the students of participant perform band performance and dance performance on there. There is usually held many performances from 10 o'clock to 18 o'clock for 3 days. It is built adjoin the booth, and the audiences can approach there. They play songs and dance using the loudspeaker. It generates the big volume in front of the open-air stage. It is shown that the sound pressure level ($L_P$) was over 100 dB at the center point (Mizuta et al. 2011). This paper shows that we analysed $L_P$ at 8 measuring points around the open-air stage.

Generally, it is hazard of inviting temporary threshold shift (TTS) that human is given the loud sound over 90 dB of the A-weighted sound pressure level ($L_A$) and over 2 hours (Miller 1974). In the campus festival, the audience stays in front of the stage for a long time. We know that the students of festival society don't explain the hazard of inviting TTS to him/her. The students don't decrease the volume of stage sound during the festival. We hope that the students understand to give the audience the big sound, and the students explain the hazard of inviting TTS to the audience. Our role is that we advise them the information of the acoustic environment last year. This paper shows the level of the sound pressure level ($L_P$) and the level of the A-weighted sound pressure level ($LA$) during the 'Shibaya' band performance on the open-air stage of the festival.

The 'Shibaya' band performance is an originality performance in our festival. It was performed over 2 hours. In the performance, the audience gathered in front of the stage. This event was united all of us in this time, and they are very excited. This performance is the final event in the campus festival.

**Figure 1:** Measuring point at the open-air stage

## MEASURING METHOD

The acoustic sound of the campus festival was measured around the campus in November 5-7, 2010. Those measuring points were 8 points in Figure 2. Two sound level meters (NL-31), and one sound level meter (NL-32) as measuring microphones made by RION Co., Ltd. Two recorders (R-09), and one recorder (R-05) made by Roland Corporation. The recorders condition is shown as follows: sampling rate was 48 kHz, and sampling bit rate was 24 bit. The center point (○) was the measuring point where the distance was 10 m from the loudspeaker near the stage, and the height was 2 m. The height was 1.2 m sven measuring points (1-7). The center point was measured all day, and each measuring point was 5 minutes different time each. The measuring sounds were the sound of the band performance, the sound of the dance performance, and the sound of the 'Shibaya' band performance.

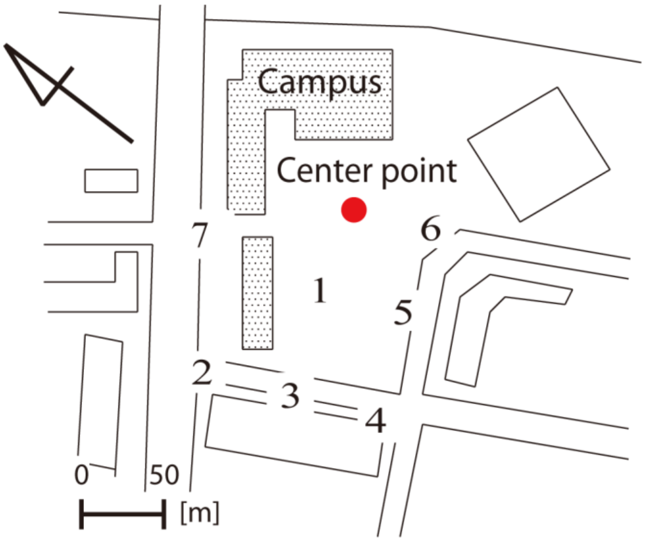


**Figure 2:** This map showed the campus and the number in the map were the measuring points

## RESULTS OF CONCERT SOUND

We defined the sound of each measuring point without the sound of the campus festival as background noise. Figure 3 shows that each level of the sound pressure level ($L_P$) was the background noise of each place, and Figure 4 shows the level of the A-weighted sound pressure level ($L_A$) of the back ground noise of each place. The sounds of the background noise were measured when the festival closed the other Sunday.

Figure 5 shows the levels of $L_P$ of the measuring points. The level of $L_P$ of the center point was 101 dB that the level averaged during the 'Shibaya' for 2 hours. The level of $L_P$ the measuring point 1 was 99 dB ($L_P$). These levels are high of sound pressure levels. Figure 6 shows the levels of $L_A$ of the measuring point by Figure 5. The level of $L_A$ of the center point was 96 dB ($L_A$). The level of $L_A$ of the measuring point 1 was 90 dB ($L_A$). The center point and the measuring point 1 were over 90 dB. It was clear that the hazard of inviting TTS in the festival, because of the audience continuous heard the 'Shibaya' in the campus.

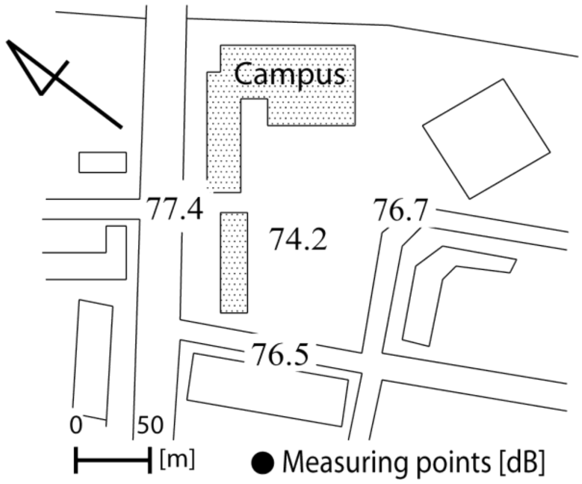


**Figure 3:** The levels of $L_P$ of back ground noise around the campus

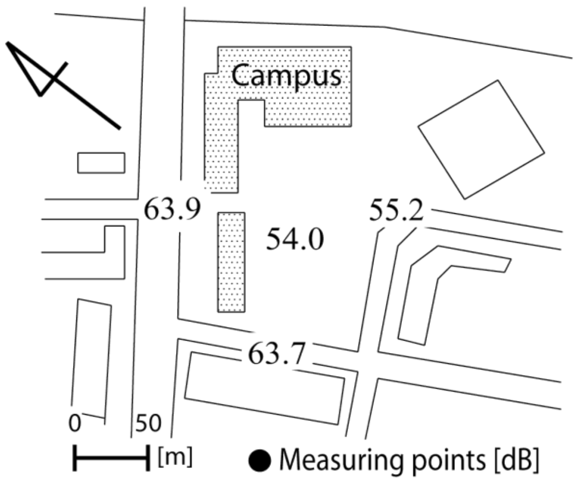


**Figure 4:** The levels of $L_A$ of back ground noise around the campus

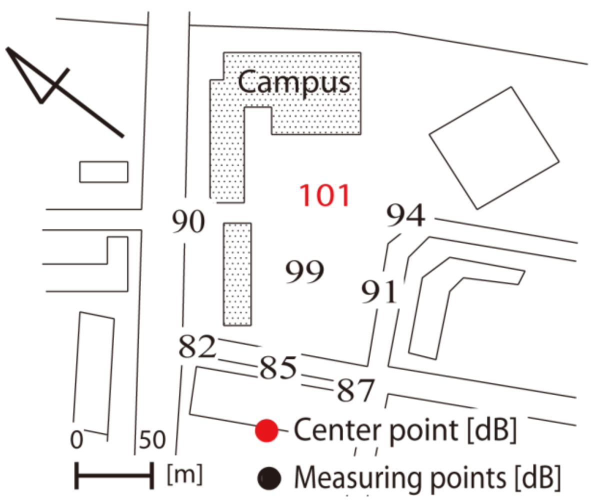


**Figure 5:** Measuring points of $L_P$ during the 'Shibaya' in the campus festival

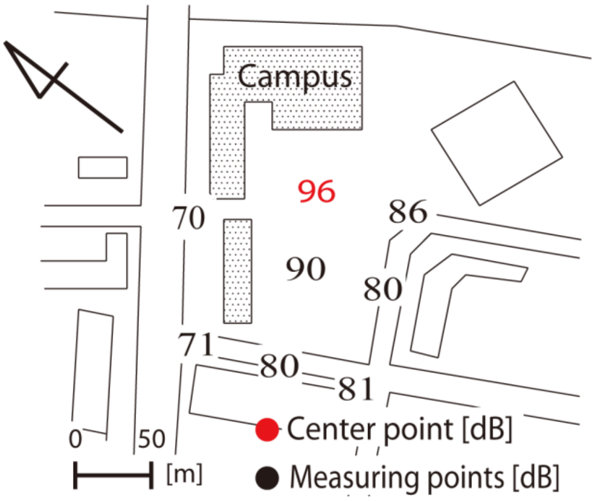


**Figure 6:** Measuring points of $L_A$ during the 'Shibaya' in the campus festival

## CONCLUSIONS

This paper shows that we measured the levels of $L_A$ of each measuring point in the campus festival. The levels of $L_A$ of each measuring point were over 90 dB in the campus. We thought that the audience was hazard of inviting of TTS through they are exposed the big sound. We are going to analyse the frequency characteristic of the spectra and to get the data of the acoustic environment to advice the students. I hope that they regard the participant the acoustic environment in the campus festival. They must explain the participant the danger of TTS.

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**The final paper was not available at deadline.**

# The determination of noise effect on hearing level and performance of teachers in primary schools

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ABSTRACT

**Objective.** Ambient background noise affects both speech intelligibility and concentration. Student and teacher performance is proven to be better in low ambient noise conditions. Noise-induced occupational hearing loss has been a long-time concern of health professionals. Research on this condition has focused mostly factory and manufacturing workers. Less attention, however, has been given to teachers exposed to classroom noise.

**Methods.** Eighty teachers (40 subjects in test group, 40 subjects in control group), with ages ranging from 25-40 years were enrolled in this study. The duration of professional activities was less than 5 years in the control group and more than 5 years in test group. In first part (non-auditory effects assessment), the blood pressure and heart rate were measured and the teachers filled a survey about other non-auditory effects. In second part (auditory effects assessment), the high frequency audiometric test was done, and their hearing threshold was measured.

**Results.** The 85 % of teachers had auditory complaints. The most common symptom was hypoacusis (45.75 %), frequently associated with tinnitus, fullness and/or vertigo. The audiometric test revealed the 32 teachers in test group had some degree of hearing loss with sloping audiometric curve.

**Conclusion.** Based on this study, the teachers are exposed to classroom noise may develop occupational hearing loss throughout their career.

# A consideration about effect of ear protector in 3-tesla MRI driving sound

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## INTRODUCTION

MRI equipment generates high level of driving sound, and it was reported that the sound causes temporary potential hearing loss to the patient (Brummett et al. 1988). The MRI driving sound makes the ear protector necessary. Therefore, it is necessary to consider the influence for the patient who uses ear protector.

MRI examination has an important role in medical diagnosis. The 1.5-tesla MRI system for whole body is popular equipment in Japan's hospitals in 2010. The 3-tesla MRI system for whole body was approved in Japan 2005. In Japan, the number of the 3-tesla MRI was 239 in 2010 ('New Medicine in Japan' 2010), because the MRI equipment obtains high quality tomogram (Wada & Ikehira 2007). The equipment utilizes a technology of tomography by the nuclear magnetic resonance (NMR) phenomenon for imaging. The gradient coils and the static magnetic field coil are necessary for imaging. The gradient coils are utilized to decide the imaging surface. The driving sound is generated in MRI examination, because strong force is generated between the static magnetic field coil and gradient magnetic field coils by switching operation of the current of the gradient magnetic field coils. The sound pressure level of 3-tesla MRI exceeds 1.5-tesla MRI on the examination table, its instantaneous sound pressure observed sometimes over 120 dB inside of the bore (Ravicz et al. 2000). The guideline of World Health Organization (WHO 2000) showed that to avoid hearing impairment, impulse noise exposures should never exceed instantaneous sound pressure of 140 dB in adults, and 120 dB in children (WHO 2000). The MRI examination makes the ear protector necessary. We have analyzed A-weighted sound pressure level of the driving sound of 1.5-tesla MRI in the case of using the ear plugs and earmuffs (Takano et al. 2004)]. Recently we measured the driving sound in near field of the equipment (Shimono et al. 2010).

Each part (head, knee, etc.) of the patient is examined in MRI examination. The position of the patient's ear is located outside the bore, in the case of the examination of knee part. However, there is no report which is measuring the driving sound on the table outside the bore. This report is shown the spectrum analysis and equivalent continuous A-weighted sound pressure level ($L_{Aeq}$) of the driving sound in the case of using the ear protector inside and outside the bore.

## MEASUREMENT OF THE DRIVING SOUND ON THE EXAMINATION TABLE

Figure 1 shows the MRI equipment Philips Achieva 3.0-tesla X-series MRI system. The MRI equipment has static magnetic field strength of 3-tesla and maximum slew rate of 200mT/m/ms. Magnetic materials are strongly attracted to MRI equipment, because MRI equipment generates high magnetic field all the time. We utilized non-magnetic microphone, wood and brass for fixation was used in the MRI examination room for measurement of driving sound. This microphone was omnidirectional microphone of electret condenser microphone (ECM) which is made by AZDEN Corporation. The vibrating membrane is polyester, the back electrode is brass, field effect transistor (FET) is 2SK123, and the cover is aluminum and resin (Muto & Yagil 2005). Figure 2 shows the measuring points which number of the points was nine. The origin was set to the center of the gantry, y-axis was set to the vertical direction and z-axis was set to the horizontal direction of the table drawing. Five points were set at intervals 10 cm inside the bore in z-axis, and four points were set at intervals 20 cm outside the bore.

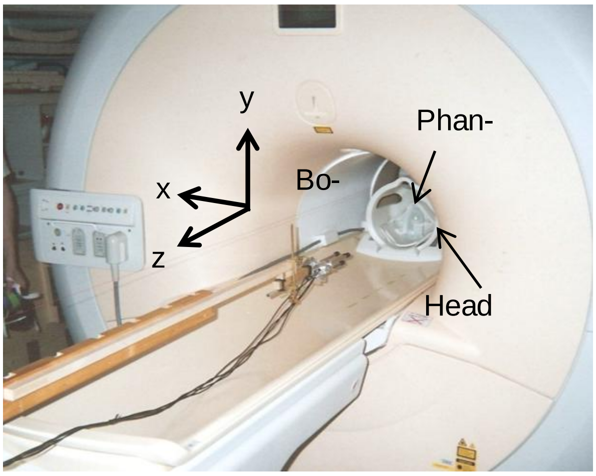


Figure 1: Measuring of the 3T MRI driving sound

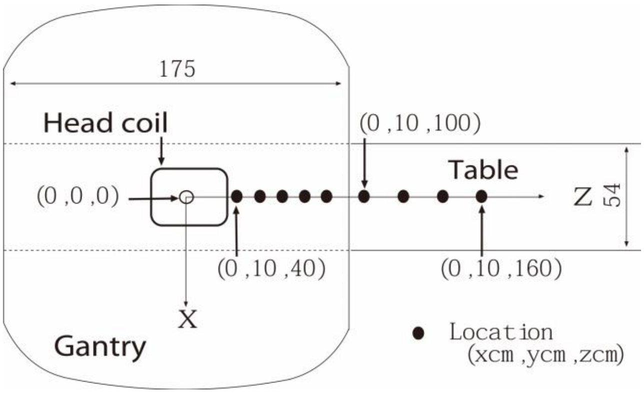


**Figure 2:** Measuring points (Top view)

The measurement conditions were shown as follows: sampling frequency was 48 kHz, the calibrator was NC-74 (calibration level 94 dB, calibration signal frequency 1,000 Hz) and NC-72 (calibration level 114 dB, calibration signal frequency 250 Hz) made by RION corporation.MRI equipment generated various driving sounds by different imaging methods. Measuring the sounds were the driving sounds of imaging methods in Slice positioning (SP), Reference scan imaging (RS), T2 weighted imaging (T2W) and Echo planar imaging (EPI). Table 1 shows the conditions of the imaging sequences. The sounds of four imaging sequences were analyzed between beginning of the driving sound and 30 seconds.

**Table 1:** Conditions of imaging sequences for measurement of driving sound. Slice positioning (SP), Reference scan imaging (RS), T2 weighted imaging (T2W), Echo planar imaging (EPI)

| | SP | RS | EPI | T2W |
|---|---|---|---|---|
| TE [ms] | 3.1 | 0.79 | 70 | 90 |
| TR [ms] | 1.4 | 4 | 3800 | 4000 |
| FOV [mm] | 250 | 450 | 230 | 230 |
| Matrix | 112×112 | 96×96 | 128×128 | 368×368 |
| Slice thickness[mm] | 2.2 | 3 | 6 | 6 |

The analysis conditions of the driving sound with an ear protector was shown as follows: The ear protector was utilized the earmuff EM-68N made by TRUSCO Corporation. The spectrum of attenuation of the earmuff was measured by Head and Torso Simulator (B&K, 4100D), its spectrum of right and left was averaged three times the measuring. Figure 3 shows sound attenuation performance of the earmuff. The analysis process of $L_{Aeq}$ of the sound that the patient hears is shown Figure 4. The $L_{Aeq}$ was calculated in frequency domain to correct gain of the ECM and to apply spectrum of the sound attenuation of the earmuff. We used Hanning window as time window. The gain in frequency domain of ECM was corrected to flat, frequency characteristic of A-weight was applied to the gain, and the sound attenuation of the earmuff was weighted to the gain.

The equivalent continuous A-weighted sound pressure level $L_{Aeq}$ is given as follows:

$$L_{Aeq} = 10\log_{10}\{\frac{1}{T}\int_{t_1}^{t_2}\frac{P_A^2(t)}{P_0^2}dt\}$$

where, $T = t_2 - t_1$ is observation time, $P_A(t)$ is A-weighted sound pressure and $P_0$ is reference sound pressure (20 μPa).

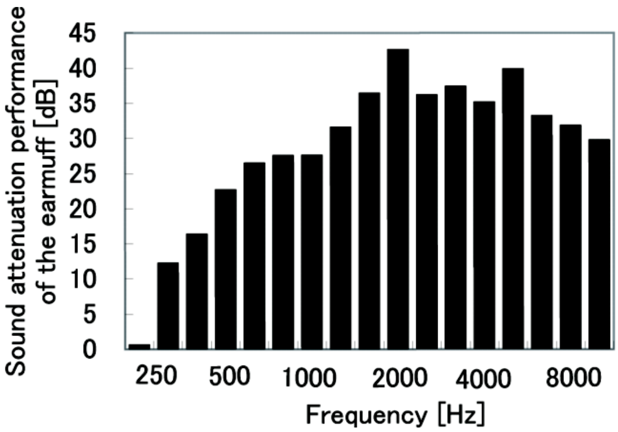


**Figure 3:** Sound attenuation performance of the earmuff

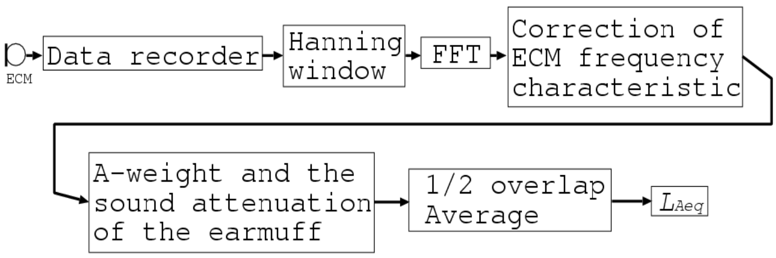


**Figure 4:** Process of equivalent continuous A-weighted sound pressure level

## ANALYSIS

### RESULT OF DRIVING SOUND ON THE EXAMINATION TABLE WITH THE EARMUFF

Figure 5 shows the waveform of the driving sound of highest level at nine measurement points. The maximum value of instantaneous sound pressure in SP, RS, T2W and EPI were 124 dB, 115 dB, 117 dB, 123 dB respectively. $L_{Aeq}$ of 30 seconds in SP, RS, T2W and EPI were 115 dB, 105 dB, 107 dB, 112 dB respectively. Figure 6 shows that the spectra of the driving sound were calculated by FFT of 4096 points. The peak frequency of SP, RS, T2W and EPI were 1,278 Hz, 1,000 Hz, 621 Hz and 786 Hz respectively, and sound pressure level ($L_P$) of SP, RS, T2W and EPI were 110 dB, 99 dB, 105 dB and 109 dB respectively.

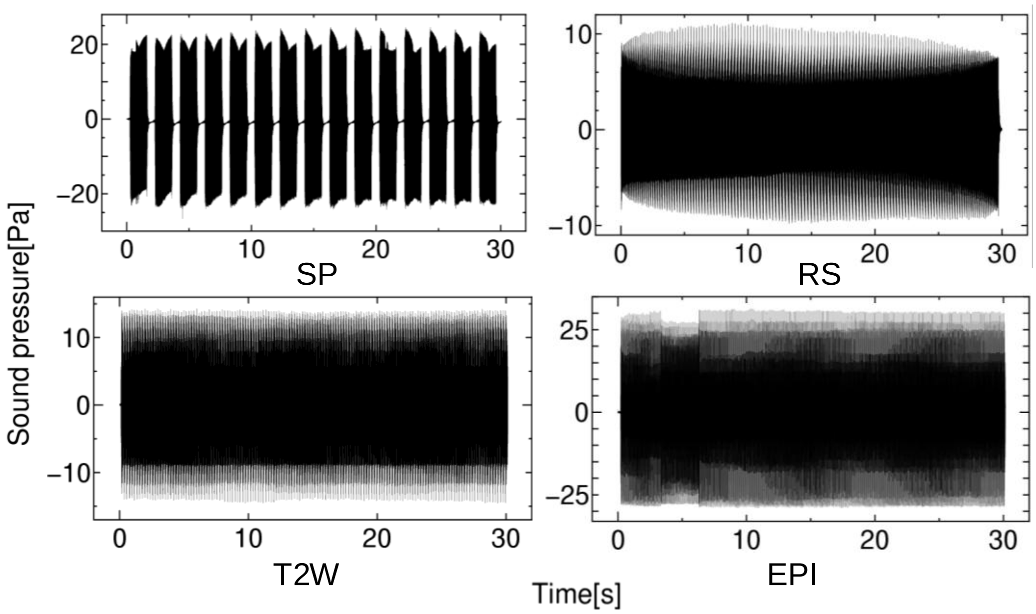


**Figure 5:** The wave forms of the driving sound

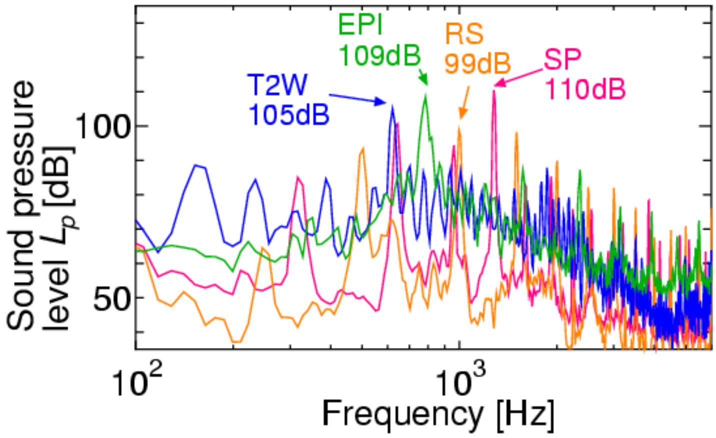


**Figure 6:** Spectrum analyses of SP, RS, T2W and EPI

Figure 7 shows the result of four kinds of the driving sound with or without the earmuff. The bar shows maximum level and minimum level which were calculated 30 seconds in nine measurement points. The average without the earmuff of SP, RS, T2W and EPI were 109 dB, 102 dB, 103 and 109 dB respectively at the nine points, and they are 77 dB, 70 dB, 81 dB and 82 dB respectively with the earmuff. Because the sound attenuation of the earmuff was depend on frequency, it is important to analyze frequency characteristic of driving sound.

Figure 8 shows 1/3 octave analysis which is the driving sound on the examination table. The spectra which had the characteristic of imaging sequence were constant though the change of a little level was shown with the measuring point. The maximum value of center band frequency of SP, RS, T2W and EPI were 1,250 Hz, 1,000 Hz, 800 Hz and 650 Hz respectively. The maximum value of center band frequency was between 650 Hz and 1,250 Hz, and it was over 27 dB in sound attenuation of the earmuff. The result was effective to protect in the basis of frequency domain of MRI driving sounds. In addition, it is effective to use unpleasant earmuffs together with earplugs. We thought that the ear protector is effective for 3-tesla MRI driving sound as well as the result of 1.5-tesla MRI.

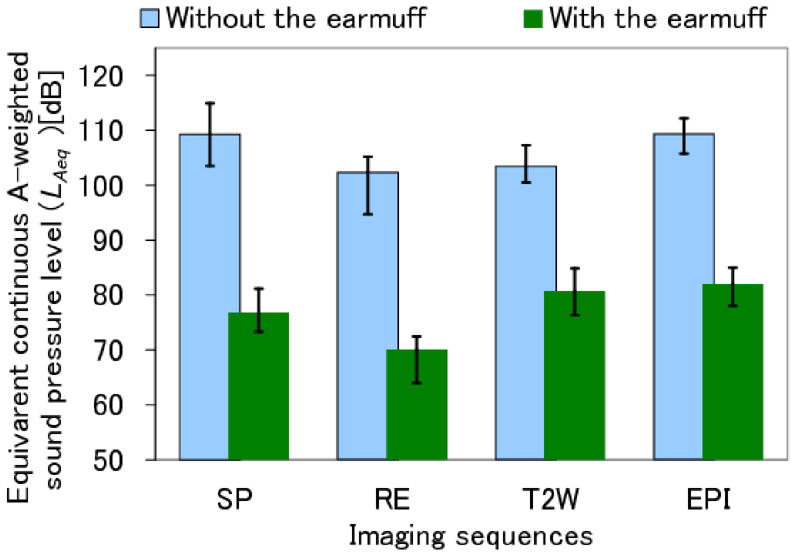


**Figure 7:** $L_{Aeq}$ of each driving sequences for subject with or without the ear muffs for 30 seconds of the driving sounds. The bar (**I**) showed maximum value and minimum value of $L_{Aeq}$ in the measurement points of nine

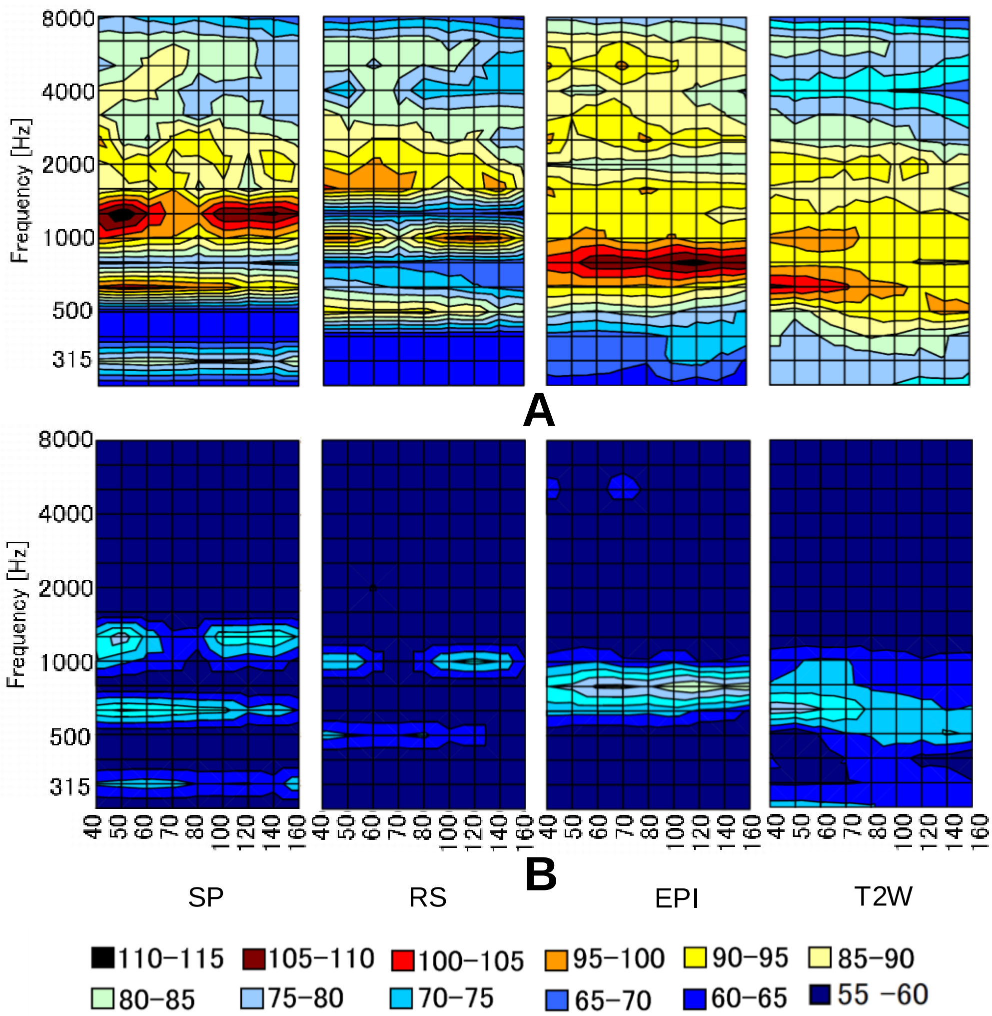


**Figure 8:** 1/3 octave analysis of Slice positioning (SP), Reference scan imaging (RS), T2 weighted imaging (T2W) and Echo planar imaging (EPI): $L_{Aeq}$ of 30 second. **A**: Analysis of the driving sounds without the earmuff, **B**: Analysis of the driving sounds with the earmuff.

## CONCLUSION

The measurement of driving sound at various positions is important for discussion of the MRI sound. This paper showed $L_{Aeq}$ of the MRI driving sound of SP, RS, T2W and EPI which were calculated 30 seconds with or without the earmuff. 1/3 octave analysis was calculated four kinds driving sound which were measurement points of nine on the examination table. MRI driving sound generated various kinds of sound that the sound was depended on imaging sequence. The earmuff was effective to protect in the basis of frequency domain of MRI driving sounds. This result contributes to the transmission system using bone conduction speaker for MRI examination (Saito & Muto 2007).

## ACKNOWLEDGEMENTS

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# Possible identification of Noise-Induced Hearing Loss susceptibility genes

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## ABSTRACT

INTRODUCTION: Overexposure to intense sound can cause permanent damage to the auditory system and result in Noise-Induced Hearing Loss (NIHL). NIHL is a complex form of hearing loss, induced by interaction between genetic and environmental factors. Some studies have led to possible identification of NIHL susceptibility genes. OBJECTIVE: To investigate whether single nucleotide polymorphisms (SNPs) in the Interleukin-1B (IL-1B) gene underlie the susceptibility to noise-induced hearing loss (NIHL). METHODS: Cross-sectional study in a population sample with 58 individuals aged over 60 years with history of occupational noise exposure in Brazil, through anamnesis and audiological evaluation and IL-1β genotyping by the PCR-RFLP technique. The variables studied were frequency of hearing loss and polymorphism (SNPs). Logistic regression analysis was used in order to control likely confusion or modification the effect of other variables on interest associations. RESULTS: Hearing loss was reported in 12.1 % of elderly with history of occupational noise exposure. 60.3 % and 22.4 % of the elderly were heterozygous and homozygous for allele 1, respectively. No significant associations between the genotypes of these SNP and NIHL were obtained in the Brazilian population. The frequency of hearing loss complaint was detected in the population under investigation, with association statistic between the presence of hearing loss complaint and IL-1B polymorphism ($\chi^2$=10.5; $p<0.05$). The 2/2 genotype was associated with hearing losscomplaint, while those who reported normal hearing presented the genotype 1/1. CONCLUSION: Our results suggest that SNP in the IL-1β is associated with hearing loss complaint in elderly with history of occupational noise exposure.

## INTRODUCTION

The onset of most hearing loss in adults is gradual and may lead to difficulty in oral language reception. According to data from ASHA - American Speech-Language-Hearing Association (ASHA 2010), currently, 28 million individuals in the United States of America present some kind of hearing loss, 80 % of them being irreversible. The data also shows that 4,6 % of the individuals between 18 and 44 years old have hearing loss, 14 % of middle-aged people, between 45 and 64, and 54 % of the population over 65. This is due to numberless factors, such as intense and/or continuous noise, inhalation of toxic substances, ingestion of ototoxic medications, metabolic and circulatory alterations, infections, traumas of diverse sources and heredity (Fanhani et al. 2007).

Aging is a dynamic process, when changes occur from the molecular to the morpho-physiological level, after maturity, leading to the organic decline, increasing susceptibility and vulnerability to diseases and to death. The genetics of aging studies the hereditary contribution of species and interaction with environment, causing biological modifications along time. Knowledge on the genetic of aging and associated diseases will provide more clinical instruments to benefit elderly people (Fanhani et al. 2007).

Overexposure to intense sound can cause permanent damage to the auditory system and result in Noise-Induced Hearing Loss (NIHL). The NIHL is a complex form of hearing loss, induced by interaction between genetic and environmental factors. Some studies have led to possible identification of NIHL susceptibility genes (Ohlemiller et al. 1999; Agrawal et al. 2009).

The genetic factors and other alterations related to noise may cause the onset of several symptoms, including hearing loss with onset slow and progressive. Subjects with Noise-Induced Hearing Loss (NIHL) have several symptoms such as hearing loss complaint, tinnitus, vertigo (Fanhani et al. 2007; Ohlemiller et al. 1999; Agrawal et al. 2009), gradual decrease or distortion in sound and alterations in speech comprehension. The NIHL is irreversible and permanent and but it the magnitude of hearing loss results from excessive exposure to noise depends on factors associated with the exposure, sound pressure level, duration, type of noise, and frequency, and the characteristics of the individual being exposed, susceptibility to NIHL, age, prior history of hearing damage. Besides occupational exposures, Hearing Loss has been associated with smoking, diabetes, hypertension, aging, health history, activities leisure-time and genetic factors (Ohlemiller et al. 1999; Marchiori et al. 2006; Agrawal et al. 2009).

Previously, the inner ear had been believed to be an immune-privileged organ isolated by the blood-labyrinth barrier (Juhn et al. 1981). Recently, however, the induction of inflammatory responses and up-regulation of pro-inflammatory cytokines in the inner ear have been reported in various damaging conditions including noise-over stimulation (Hirose et al. 2005; Tornabene et al. 2006; Ladrech et al. 2007; Keithley et al. 2008). In fact, one of the pro-inflammatory cytokines, tumor necrosis factor α (TNF-α) induces the recruitment of pro-inflammatory cells into the cochlea (Keithley et al. 2008).

Another pro-inflamatory cytokine, IL-6, is produced by a variety of cell types during tissue damage, infection and inflammatory diseases (Johnston et al. 2005; Loddick et al. 1998; Yang et al. 2005).

Cochlear lateral wall fibrocytes are also known to produce inflammatory mediators, as shown by several studies. For example, several in vitro studies have reported that cultured cochlear lateral wall fibrocytes produced IL-6 and other inflammatory agents, including chemoattactants for inflammatory cells, when stimulated by IL-1β or TNF-α (Yoshida et al. 1999; Ichimiya et al. 2003).

The structure and expression of a cytokine can be influenced by genetic variation, resulting in evident pathologic consequences (Smith & Humphries 2009). Functionality of single nucleotide polymorphisms (SNPs) with regard to gene expression is an important subject in disease-association studies. Numerous findings related to the functionality of SNPs of cytokine genes have been reported, and several studies have examined these SNPs as risk factors for inflammation (Duff 2000).

The purpose of the study was to investigate whether single nucleotide polymorphisms (SNPs) in the Interleukin-1β (IL-1β) gene underlie the susceptibility to noise-induced hearing loss.

## METHODS

A cross-sectional study was carried out at the CCS located in UNOPAR in Londrina, Brazil. The study protocol was approved by the bioethical committee of the UNOPAR University. The subjects were sent by EELO project and were given the informed consent letter.

The population consisted of sample 101 individuals aged over 60 years with history of occupational noise exposure in Brazil, evaluated through anamnesis and audiological evaluation and IL-1β genotyping.

The anamnesis included questions about age, gender, hearing loss complaint, work-related noise exposure history and medical history.

The audiological evaluation was performed individually in a sound-proof booth with an Interacoustics Audiometer.

The evaluation IL-1β genotyping was performed by the PCR-RFLP technique. Briefly, genomic DNA was extracted from the blood samples using the genomic DNA extraction kit (Invitrogen, USA). Samples were stored at -70 ºC until further use. IL-1β genotyping was carried out as described by Al-Qawasmi et al. (Al-Qawasmi et al. 2003). The DNA samples were subjected to the polymerase chain reaction amplification, using the following primers: forward – 5' CTC AGG TGT TCC TCG AAG AAA TCA A 3' and reverse 5' GCT TTT TTG CTG TGA GTC CCG 3'. Polymerase chain reaction conditions were denaturation at 95 °C for 5 min, followed by 35 cycles of 95 °C for 1 min, 67 °C for 1 min, and 72 °C for 1 min, and a final extension at 72 °C for 10 min. The amplified DNA was subjected to the restriction fragment length polymorphism technique, with digestion by *Taq*I, generating the following patterns: 1 allele, 85 and 97 bp; 2 allele 182 bp. These fragments were visualized on 4 % agarose gels, instead of polyacrylamide gels as described in the original article.

The variables studied were IL-1β genotyping and hearing complaints in elderly with history of occupational noise.

To select the variables in order of their P values, with the smallest first, was performed association statistic. The Logistic regression was used in order to control likely confusion or modification of effect to the other variables on interest associations.

## RESULTS

Of the total of 101 elderly with mean age of 71.3 (SD= 4.2) included in this study, 57.4 % were female gender, 52.5 % of them hearing loss complaint and 30.7 % had history of occupational noise exposure (Table 1).

It has been found a significant association between hearing loss and noise exposure ($\chi^2$=56,31; p< 0.01). The hearing loss was reported in 100 % of elderly with history of occupational noise exposure (Table 2).

As shown in Table 3, 56.4 % and 12.9 % of the elderly were heterozygous and homozygous for allele 1, respectively. No significant associations were found between the genotypes of this SNP and NIHL in this population.

The frequency of hearing loss complaint was detected in the population under investigation (Table 4). It was found an association statistic between the presence of hearing loss complaint and IL-1B polymorphism ($\chi^2$=10.5; p<0.05). The frequency of 2/2 genotype in the elderly with hearing loss complaint was significantly higher than in the elderly who reported normal hearing and presented the 1/1 genotype.

**Table 1:** Characteristics of the elderly

| *Characteristic* | *N* | *%* |
|---|---|---|
| Gender | | |
| Male | 43 | 42.6 |
| Female | 58 | 57.4 |
| Complaint loss hearing | | |
| Yes | 53 | 47.5 |
| No | 48 | 52.5 |
| History of occupational noise exposure | | |
| Yes | 31 | 30.7 |
| No | 70 | 69.3 |

**Table 2:** Association between Noise-Induced Hearing Loss (NIHL) and history of occupational noise exposure in elderly

| | *History of occupational noise exposure* | | | |
|---|---|---|---|---|
| | Yes | | No | |
| | N | % | N | % |
| NIHL | | | | |
| Yes* | 20 | 100 | 0 | 0 |
| No | 11 | 13.6 | 70 | 86.4 |

*$\chi^2$=56.31; p<0.01

**Table 3:** The distribuition of IL-B genotypes in NIHL elderly

| *Genotypes* | *N* | *%* |
|---|---|---|
| Homozygote 1/1 | 13 | 12.9 |
| Homozygote 2/2 | 31 | 30.7 |
| Heterozygote | 57 | 56.4 |

**Table 4:** Association between the presence of hearing loss complaint and IL-1B polymorphism

| | *Complaint "hearing loss"* | |
|---|---|---|
| | Yes | No |
| Genotypes* | | |
| Homozygote - 1/1 | 5 (38.5) | 8 (61.5) |
| Homozygote - 2/2 | 22 (71.0) | 9 (29.0) |
| Heterozygote | 26 (45.6) | 31 (54.4) |

*$\chi^2$=10.5; p<0.05

There are still limited data about genetic polymorphisms that may be involved in the susceptibility to hearing loss and an increased probability of NIHL. Elderly who had a history of occupational noise may help answer questions regarding the genetic susceptibility to occupational noise.

Proinflammatory cytokines are produced in various organ after tissue damage not only experimental immune-response models, but also in various types of insults including infection, ischemia, trauma, cryo-ablation, and burns (Berti et al. 2002; Pier et al. 2004), by various types of cells, including residential immune-related cells (such as leukocytes, macrophages, microglia, dentritic cells), neurons and glia in the central nervous system (Fujioka et al. 2006).

As disruption of the blood-labyrinth barrier is associated with increased permeability of blood vessels in inner ear, inflammation may be related to the etiology of these inner ear diseases (Keithley et al. 2008).

The studies from Hirose et al. (2005) and Fujioka et al. (2006) have pointed out the possibility of inflammatory changes in noise overstimulated cochleae. Interestingly, Fujioka et al. (2006) observed the expression and relative induction of IL-1B and TNF-α before IL-6 RNA expression after noise exposure. Previous reports showed that cochlea lateral wall fibrocytes produced IL-6 when stimulted by IL-1B and TNF-α in vitro (Ichimiya et al. 2003).

Several published reports suggested the involvement of IL-1 family and TNF-α in damage cochleae (Satoh et al. 2002; Wang et al. 2003; Komeda et al. 1999). Although the mechanism and function of these cytokines in NIHL are still obscure, it is known that the structure and expression of a cytokine can be influenced by genetic variation, resulting in evident pathologic consequences (Smith & Humphries 2009). Functionality of single nucleotide polymorphisms (SNPs) with regard to gene expression is an important subject in disease-association studies and are associated with avoiding disease in late life, or their frequency has been shown to differ between younger and older individuals (Hadley et al. 2000).

## CONCLUSIONS

The results obtained in this study suggest that SNP in the IL-1B is associated with hearing loss complaint in elderly with history of occupational noise exposure.

It is important to critically evaluate the results and the whole study. The present study has certain limitations that need to be taken into account when considering the study and its contributions. The limitation has to do with the extent to which the findings can be generalized beyond the cases studied. The number of cases is too limited for broad generalizations. However, further evaluations, however, are needed to replicate the findings in different contexts and surroundings.

Although with the few people, the selection criterion and the good quality of the research it could also be argued that for the future research on this topic with more people.

The conclusions as well as the limitations of this study also bring forth some fruitful and interesting possible avenues for future research that might be needed in relation to the theme of the study. The most important avenue for future research obviously lies in verification the possible identification of Noise-Induced Hearing Loss susceptibility genes.

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# Auditory effects of noise exposure during magnetic resonance imaging

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## INTRODUCTION

Various types of acoustic noise are produced during the operation of MR systems. The problems associated with acoustic noise for patients and healthcare workers include simple annoyance, difficulties in verbal communication, heightened anxiety, temporary hearing loss, and potential permanent hearing impairment (Brummett et al. 1988; Quirk et al. 1989; Laurell 1992; Philbin et al. 1996; Kanal et al. 1988, 1990; Shellock & Kanal 1991; Shellock et al. 1992). Acoustic noise may pose a particular hazard to specific patient groups who may be at increased risk. Patients with psychiatric disorders and elderly and pediatric patients may be confused or suffer from heightened anxiety (Quirk et al. 1989). Sedated patients may experience discomfort due to high noise levels. Certain drugs are known to increase hearing sensitivity (Laurell 1992). Neonates with immature anatomical development may have an increased response to acoustic noise. For example, significant alterations in vital signs of newborns have been reported during MRI examinations, which may be attributed to acoustic noise (Philbin et al. 1996).

Acoustic noise levels during echoplanar imaging (EPI) have been reported to increase significantly pure tone hearing thresholds in the optimal frequency hearing range (i.e., 0.1–8 kHz) (Ulmer et al. 1998). These effects vary across the frequency range. The threshold changes according to the characteristics of the sequence-generated acoustic noise (Ulmer et al. 1998). The gradient magnetic field is the primary source of acoustic noise associated with MR procedures (Goldman et al. 1989; Hurwitz et al. 1989). This noise occurs during the rapid alternations of currents within the gradient coils. These currents, in the presence of a strong static magnetic field of MR system, produce significant (Lorentz) forces that act upon the gradient coils. Acoustic noise, manifested as loud tapping, knocking, or chirping sounds, is produced when the forces cause motion or vibration of the gradient coils as they impact against their mountings which, in turn, also flex and vibrate. Alteration of the gradient output (rise time or amplitude) caused by modifying the MR imaging parameters will cause the level of gradient-induced acoustic noise to vary. This noise is enhanced by decreases in section thickness, field of view, repetition time, and echo time. The physical features of the MR system, especially whether or not it has special sound insulation, and the material and construction of coils and support structures also affect the transmission of the acoustic noise and its subsequent perception by the patient and MR system operator. Hurwitz et al. (1989) reported that the sound levels varied from 82 to 93 dB on the A-weighted scale and from 84 to 103 dB on the linear scale. Table 1 shows the relationship between the noise duration and recommended permissible sound levels for occupational exposures.

**Table 1:** Permissible exposure levels to acoustic noise

| Noise duration / day (hours) | Sound level (dB A) |
|---|---|
| 8 | 90 |
| 6 | 92 |
| 4 | 95 |
| 3 | 97 |
| 1.5 | 100 |
| 1 | 102 |
| 0.5 | 105 |
| 0.25 | 115 |

The U.S. Food and Drug Administration indicates that the acoustic noise levels associated with the operation of MR systems must be below the level of concern established by pertinent federal regulatory or other recognized standards setting organizations. If the acoustic noise is not below the level of concern, the manufacturer of the MR system must recommend steps to reduce or alleviate the noise perceived by the patient. No recommendations exist for non-occupational or medical exposures. In general, the acoustic noise levels recorded by various researchers in the MR environment have been below the maximum limit permissible by the Occupational Safety and Health Administration (OSHA) of the United States. This is particularly the case when one considers that the duration of exposure is one of the most important physical factors that determine the effect of noise on hearing. These recommended limits for acoustic noise produced during MRI procedures are based on recommendations for occupational exposures that are inherently chronic exposures with respect to the time duration. Of note is that comparable recommendations do not exist for non-occupational exposure to relatively short-term noise produced by medical devices.

AIM

To determine if there is any noise induced threshold shift resulting from the noise exposure from Magnetic Resonance Imaging (MRI).

METHOD

**Instruments used**

- MAICO MA 53 audiometer with Telephonics TDH 49P headphones and Radio ear B-71 bone vibrator
- MAICO ERO SCAN OAE Test system
- MRI instrument used were General Electric Sigma Contour 0.5 Tesla and General Electric 1.5 Tesla HDxt

**Participants**

A total of 30 adult participants (17 for 0.5 Tesla MRI and 13 for 1.5 Tesla MRI ) who were scheduled for MRI anticipated to require at least 20 min of imaging time were included in this study. Informed consent was obtained from all patients after the nature of the procedure was fully explained.

**Procedure**

All the subjects with positive history of ear pathology, medical history for otological damage, noise exposure or the use of any ototoxic drugs were excluded from this study. An otoscopic examination was performed on each patient to check the status of the external auditory meatus and the tympanic membrane. Then, a screening OAE test was done using ERO SCAN, Etymotic Research, MAICO OAE Screening instrument to check the status of the outer hair cells of the cochlea. All the evaluations were carried out in a quiet room with ambient noise within permissible limits as per ANSI (1977) using biological calibration. Then the baseline pure tone air and bone conduction thresholds were determined employing a step size of 2 dB for each ear using the MAICO MA-53 audiometer with TDH 49P headphones and Radio ear B-71 bone vibrator. The bone conduction thresholds were also found out to rule out any middle ear condition noticed through the Air Bone Gap (ABG). The test frequencies were 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 8 kHz. All the subjects had normal hearing air conduction thresholds (20 dBHL or below across frequencies 250 Hz to 8 kHz). The first MRI instrument used in the present study is a General Electric Sigma Contour 0.5 Tesla device. The average of noise exposure ranged from 30 min to 1 hour 30 min depending on the type of scan (determines the number and type of sequences for it) and patient‘s status; the time taken for the MRI of pelvis is found to be approximately 80 min for 8 sequences, for knee is 40 to 60 min for 6 sequences, for spine is 30 to 45 min for 5 sequences, for shoulder is 60 to 90 min and for brain is 30 to 45 min for 5 sequences. Out of the 17 subjects 5 had pelvis scan, 2 had knee scan, 6 had spine scan, 3 had shoulder scan and 1 had brain scan.

The second MRI instrument used in the present study is General Electric 1.5 Tesla HDxt. The participants who were scheduled for brain scans were only taken up because ear muff could be provided for all the other types of scan in this MRI instrument except for brain scans since it would distort the scan image. The time taken for the brain scan was approximately 20-30 min which all 13 participants were scheduled for. The post MR imaging audiometric threshold estimation was done as soon as possible after the completion of the MRI study. The average time taken to initiate the test after the termination of the MRI was approximately 5-10 min. Mean, Standard Deviation (S.D.) of the pre, post and between different MRI procedures were calculated. Further to estimate if the mean difference is significant, paired ‘t’-test was used using SPSS version 5.

RESULTS AND DISCUSSION

The literature reveals that various studies have found that the noise levels during the MRI procedure causes Temporary Threshold Shift. Noise levels in the scanning room were done using Brüel & Kjær Sound Level Meter and revealed that average $L_{eq}$ levels were 129 dBSPL for 20 min. The hearing thresholds obtained pre and post MRI procedure are presented and discussed below. The mean and Standard Deviation (S.D.) for baseline AC thresholds of the 17 participants (34 ears) for 0.5 T MRI and 13 participants (26 ears) for 1.5 T MRI are as shown in Table 2.

**Table 2:** Mean and S.D. for pre MRI AC thresholds

| MRI instrument used | Frequency (Hz) | 250 | 500 | 1 k | 2 k | 4 k | 8 k |
|---|---|---|---|---|---|---|---|
| 0.5 T | Mean (dBHL) | 14.53 | 14.18 | 14.53 | 14.18 | 14.06 | 14.47 |
| | S.D. | 3.98 | 3.69 | 4.69 | 3.83 | 4.76 | 6.68 |
| 1.5 T | Mean (dBHL) | 12.46 | 11.84 | 14 | 13.69 | 14 | 14.46 |
| | S.D. | 2.02 | 2.37 | 2.16 | 1.60 | 2.16 | 1.66 |

The mean and S.D. of difference in thresholds between the pre and post MRI thresholds are tabulated above for the different scan procedures are as shown in Table 3.

**Table 3:** Mean and S.D. for post MRI AC thresholds

| MRI instrument used | Frequency (Hz) | 250 | 500 | 1 k | 2 k | 4 k | 8 k |
|---|---|---|---|---|---|---|---|
| 0.5 T | Mean (dBHL) | 15.94 | 15.27 | 14.09 | 15 | 22.65 | 20.47 |
| | S.D. | 4.94 | 4.19 | 5.18 | 5 | 5.90 | 7.25 |
| 1.5 T | Mean (dBHL) | 12.15 | 12.30 | 14.76 | 14.46 | 21.07 | 21.38 |
| | S.D. | 2.23 | 2.13 | 2.08 | 2.02 | 2.39 | 3.30 |

The mean values between the pre and post MRI thresholds (for both 0.5 T and 1.5 T MRI) shows a difference at 4 kHz and 8 kHz, and to check if there is a statistical significant difference, paired 't'-test was performed and it was observed there was a significant increase ($P < 0.001$) in the air conduction thresholds at 4 kHz and at 8 kHz ($P < 0.001$) after MRI. The frequencies from 250 Hz to 2 kHz did not show any statistically significant difference after exposure to acoustic noise of MRI. This shows that there is a noise induced Threshold Shift in the normal hearing subjects after the MRI which suggests that the noise exposure during the MRI has damaging effects on the auditory system. These findings can be correlated to the finding of Brummett et al. (1998) where in a total of 14 adult patients were subjected to MRI study of 0.35- Tesla equipment, wherein significant threshold shifts of 15 dB or above were found in frequencies 560 Hz, 4 KHz, 6 KHz and 8 KHz in 43 % of patients. Ear plugs, when properly used can abate noise by 10-30 dB, which is usually an adequate amount of sound attenuation for the MR environment. The use of disposable ear plugs has been shown to provide a sufficient decrease in acoustic noise that in turn would be capable of presenting the potential temporary hearing loss associated with MRI procedures (Bandettini et al. 1992). Passive noise control techniques of using Ear Protective Devices (EPD) provide poor attenuation of noise transmitted to the patient through bone conduction.

## CONCLUSION

Noise originating from MRI easily reaches sound pressure levels 110 dB and higher (Moelker et al. 2003), a peak $L_{eq}$ of 119 dBSPL was found in the current study and such high levels of noise may damage the auditory system (29 CFR 1910.95, Occupational Noise Exposure). In our study we found that noise exposure during MRI could potentially damage the human auditory system causing a significant noise induced threshold shift at 4 kHz and 8 kHz. Thus, there is a need for effective hearing protective devices and also the necessity to reduce the generation of acoustic noise during MRI through hardware modifications of the scanner and room acoustics, in order to prevent long-term auditory effects.

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# Classroom acoustics and self-reported noise exposure as determinants of fatigue after work, job satisfaction and intentions to quit the job among school teachers

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## ABSTRACT

Background: Noise is a source of disturbance and annoyance among school teachers, even though the sound levels are well below the level associated with increased risk of hearing impairment. However, little is known about other effects associated with noise exposure in this group and to what extent the acoustic environment contributes. Objective: The study aimed at identifying the impact of classroom acoustics and self-reported noise on fatigue after work, job satisfaction, and intentions to quit the job among 283 school teachers in 10 public schools in Copenhagen, Denmark. Methods: Questionnaire survey combined with independent expert assessments of the schools acoustical quality and complemented with measurements of classroom reverberation times. Results: Self-reported noise exposure was significantly associated with low job satisfaction and with increased fatigue after work, particularly the fatigue dimension lack of energy. Working in schools with classrooms characterized by relatively long reverberation time (0.62-0.73 s) compared to schools with classrooms of short reverberation time (0.41-0.45 s) was associated with low job satisfaction, lack of energy, and an increased risk of considering quitting the job. Conclusions: Both self-reported noise exposure and classroom acoustics were independently associated with negative evaluations of the working environment.

## BACKGROUND

The cognitive demands needed for teaching in schools increases in background noise and under poor acoustical conditions, for example, speech intelligibility is decreased (Picard & Bradley 2001) cognitive processes are impaired (Beaman 2005; Beaman & Holt 2007; Kjellberg et al. 2008; Ljung & Kjellberg 2009). Furthermore, in highly reverberating classrooms noise tends to breed noise (Nijs et al. 2008; MacKenzie & Airey 1999; Oberdörster & Tiesler 2006), adding voice problems and annoyance to the list of adverse effects (Åhlander et al. 2010; Pekkarinen et al. 1992; Enmarker & Boman 2004). However, little is known about the influence of noise and poor acoustical working conditions on teachers' fatigue, job satisfaction and intentions to quit the job. Fatigue is important because it is likely to influence performance in both work and home related activities. Likewise, job satisfaction presumably also has an influence on work performance, and both job satisfaction and long term fatigue are associated with increased sickness absence (Eshøj et al. 2001; Janssen et al. 2003; Duijts et al. 2006). Finally, quitting the job is a way to cope with poor working conditions. All these adverse effects are important to study because they costly for the individual, the school, and for the society in general. The purpose of the present study was to investigate these outcomes in school teachers coming from schools characterized by different classroom acoustical conditions. Our hypotheses were that long classroom reverberation times and high perceived noise exposure were associated with lower job satisfaction, more fatigue after work, and expressing interest in leaving the job.

## METHODS

### Participants

Teachers from 10 schools in Copenhagen were invited to participate in the study. Of the 419 potential respondents, 283 (67.5 %) filled in a questionnaire on background information, noise exposure, disturbance by noise, job satisfaction, fatigue and intentions to quit the job (as well as other topics).

### Acoustic characterization of the schools

An acoustical screening procedure was applied to ascertain that the 10 schools were eligible for the study and that all teachers at the same school shared the same acoustical classroom working environment: Each school was inspected by 2 acousticians and based on the classroom geometry, the type of ceiling, and amount of sound absorbing materials on the walls, they classified the classroom according to the reverberation time (RT). The RT evaluation was verified by control measurements of RT in each school (125-4,000 Hz) in 2-3 classrooms without pupils. The schools were classified as “Short RT” (3 schools), “Medium RT” (3 schools) and “Long RT” (4 schools) based on the classroom RT evaluation. The average RT of the “Short RT” schools were 0.43 s (range 0.41-0.45 s), in the “Medium RT” schools 0.54 s (0.51-0.55) and in the “Long RT” schools 0.67 s (0.62-0.73 s).

### Noise exposure

Perceived noise exposure was assessed by an item that read “Are you exposed to noise that disturbs you when you are teaching?” A trichotomous outcome was constructed by combining the 6 response categories into Never/rare (“Never” and “Rarely or very little”), ¼-½ of the work time (“Approximately ¼ of the time” and “Approximately ½ of the time”), and ≥¾ of the time (“Approximately ¾ of the time” and “Almost all of the time”).

### Fatigue

A Danish translation of the Swedish Occupational Fatigue Inventory-20 (SOFI-20) was used to measure work related fatigue. The instrument encompasses 20 items that are responded to on seven-point scales (score ranges from zero to six) with verbally anchored endpoints “not at all” and “to a very high degree” (Åhsberg 2000). Factor analysis with varimax rotation and applying loading>0.5 as criterion resulted in four fatigue dimensions that were named *Physical discomfort and exertion* (6 items, Cronbach’s alpha = 0.84), *Lack of energy* (4 items, Cronbach’s alpha = 0.93), *Lack of motivation* (4 items, Cronbach’s alpha = 0.89), and *Sleepiness* (4 items, Cronbach’s alpha = 0.86).

### Job satisfaction

Job satisfaction was assessed by a single item that read, “All in all, how satisfied would you say you are with your job?” with response categories 1 = no, or very little, 2 = little, 3 = somewhat, and 4 = very much.

### Intentions to quit the job

Teachers were asked if they were thinking about leaving their job. Response options were “No” and “Yes”, the latter were divided into subcategories (“Leaving for a position at another school”, “Completely leaving the teaching profession”, “Retirement”). Respondents, who considered leaving due to retirement, were excluded from the analyses because it was assumed that retirement was likely to be determined mainly by age rather than by noise exposure.

## RESULTS

Crude associations of acoustical classification of the school and perceived noise exposure with job satisfaction and fatigue dimensions are shown in Table 1. The results are expressed as the estimated difference between groups with “Short RT” as reference category for the acoustical classification, and “Never/Rarely” as reference category for perceived noise exposure.

In Table 2 are presented the risk (odds ratio, OR) of expressing risk in relation to the acoustical classification and noise exposure. Reference categories are the same as those in Table 1.

**Table 1:** Crude associations (ANOVA) of school acoustical classification and perceived noise exposure with teachers’ job satisfaction and fatigue after work

| | Acoustical classification | | | | Perceived noise exposure | | | |
|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | P | | Mean | SD | P |
| Job satisfaction | Medium versus short RT | -0.09 | 0.09 | 0.235 | 1/4-1/2 of the time versus never/rare | -0.35*** | 0.09 | <0.001 |
| | Long versus short RT | -0.33*** | 0.09 | <0.001 | >1/2 of the time versus never/rare | -0.48*** | 0.11 | <0.001 |
| Physical discomfort and exertion | Medium versus short RT | -0.03 | 0.13 | 0.729 | 1/4-1/2 of the time versus never/rare | 0.20 | 0.13 | 0.112 |
| | Long versus short RT | 0.17 | 0.12 | 0.135 | >1/2 of the time versus never/rare | 0.34* | 0.16 | 0.029 |
| Lack of energy | Medium versus short RT | 0.08 | 0.25 | 0.520 | 1/4-1/2 of the time versus never/rare | 1.09*** | 0.25 | <0.001 |
| | Long versus short RT | 0.49* | 0.24 | 0.037 | >1/2 of the time versus never/rare | 1.80*** | 0.29 | <0.001 |
| Lack of motivation | Medium versus short RT | -0.07 | 0.20 | 0.779 | 1/4-1/2 of the time versus never/rare | 0.76*** | 0.20 | <0.001 |
| | Long versus short RT | 0.17 | 0.19 | 0.299 | >1/2 of the time versus never/rare | 1.07*** | 0.24 | <0.001 |
| Sleepiness | Medium versus short RT | -0.16 | 0.22 | 0.875 | 1/4-1/2 of the time versus never/rare | 0.72*** | 0.22 | 0.001 |
| | Long versus short RT | 0.20 | 0.21 | 0.267 | >1/2 of the time versus never/rare | 0.92*** | 0.27 | 0.001 |

**Table 2:** Crude risk (odds ratio, OR) of expressing interest in quitting the job in relation to acoustical classification of the school and perceived noise exposure of the teacher (logistic regression)

| Acoustical classification | | | | | Perceived noise exposure | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | OR | Lower | Higher | P | | OR | Lower | Higher | P |
| Medium versus short RT | 1.10 | 0.47 | 2.57 | 0.829 | 1/4-1/2 of the time versus never/rare | 2.62 | 0.97 | 7.08 | 0.058 |
| Long versus short RT | 2.97** | 1.40 | 6.30 | 0.005 | >1/2 of the time versus never/rare | 5.44** | 1.86 | 15.86 | 0.002 |

## DISCUSSION

The results are in accordance with the assumptions of a negative impact on school teachers' wellbeing from noise and poor acoustical working conditions. Thus, our hypotheses regarding the acoustical classification were fulfilled for job satisfaction, lack of energy and interest in quitting the job. With regard to perceived noise exposure the hypotheses were fulfilled with regard to all variables investigated.

Interestingly, Klatte et al. (2010) had the focus on the pupils when the studied the association between well-being and classroom acoustics. They found the both the social climate in the class and the pupils perceived relation with the teacher was negatively affected by long classroom RT.

It well known that classroom noise is a cause of annoyance among teachers (for example Enmarker & Boman 2004). We have previously shown, in the same group of teachers, that disturbance attributed to noise in the class was significantly associated with school acoustical classification and that the disturbance ratings were highest in schools classified as "Long RT" (Kristiansen et al. 2010). Noise and classroom acoustics is not school teachers' sole concern. To make priorities among the resources to be used to secure or improve the working environment, it is necessary that the most significant consequences associated with noise and poor acoustics are identified and evaluated. The findings presented here extend on the previous findings in that they indicate that noise and poor acoustical working conditions have a deeper impact on school teachers' perceived working environment than simply causing noise annoyance. The effects of noise exposure and poor acoustical working conditions studied here are likely to transform into economically significant consequences, such as decreased work performance, increased sickness absence and higher job turnover. Further studies are needed to illuminate such effects.

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# Noise and hearing loss in developing countries

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ABSTRACT

Environmental noise is soaring in developing countries due to an ever increasing level of transportation and growing numbers of people living in so called mega-cities of the world, which are primarily in developing countries. Occupational noise appears to be reducing in the developed world due to improved manufacturing processes and greater automation but continuing use of old machinery and systems in the developing countries, the situation has not improved. The global annual incidence of noise induced hearing loss (NIHL) is estimated to be 2 new cases per 1,000 older workers. It has been suggested that the burden of NIHL is 0.3m in developed nations whilst it is 3.8m in the developing world. Furthermore, the provision of hearing conservation programmes, hearing aids and social support networks are lacking in the developing countries. This paper will examine the current available literature to provide an overview of the situation around the globe.

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## D-methionine in preventing noise-induced hearing loss

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ABSTRACT

Oxidative stress in the cochlea is considered to play an important role in noise-induced hearing loss. The purpose of this study is to understand the mechanism underlying the noise induced increase in reactive oxygen species (ROS) in the inner ear. The changes in superoxide dismutase (SOD), catalase, lipid peroxidation (LPO) in the cochlea and the auditory brainstem response (ABR) were measured 1, 7 and 14 days after noise exposure (4 kHz octave band at the intensity of 118 dB SPL for 8 hours) in C57BL/6 mice. In addition we also investigated the role of an antioxidant D-methionine (D-met) in preventing the noise-induced oxidative stress and hearing loss.

The findings of this study indicate that the time dependent alterations in scavenging enzymes facilitate the production of free radicals and D-met drug is effective in attenuating the noise-induced oxidative stress and associated functional loss in mice cochlea.

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# Self-reported noise-disturbance and hearing of schoolteachers in relation to audiometric determinations

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## ABSTRACT

We have previously observed that poor classroom acoustics (long reverberation time) and other work related conditions contribute to the perceived noise exposure of schoolteachers and the disturbance attributed to noise in the classroom. The present study aimed to investigate to what extent the self-reported noise exposure and disturbance attributed to noise in the classroom were associated with high noise levels and hearing deficiency. Therefore, self-reported noise exposure, disturbance attributed to noise in class and hearing loss was compared to determinations of pure-tone audiometry (PTA) and distortion product oto-acoustic emissions (DPOAE). There was a statistically significant association between self-reported noise exposure and the degree of disturbance attributed to noise in the classroom, respectively, and measurements of DPOAE at high frequencies, and contrary to expectations higher scores in the disturbance of teaching by noise was associated with better hearing.

## INTRODUCTION

Noise disturbance has increased over the last decades among Danish schoolteachers, and although the noise levels seldom reaches noise levels with risk of noise induced hearing loss (Oberdörster & Tiesler 2006), there has also been an increase in the reports of hearing problems, tinnitus, and hyperacusis. These trends have coincided with an increase in the age of schoolteachers, and it has therefore been hypothesized that complaints of noise disturbance and problems of hearing were linked to the difficulties of hearing among the older schoolteachers in classrooms with low acoustic quality. One of the mechanisms in breeding the general noise levels in classrooms is that talkers tend to increase voice levels when talking in background noise or in reverberating rooms, an effect known as the Lombard effect (Nijs et al. 2008). This has been demonstrated by measurements of background noise levels in classrooms, which shows that noise levels are higher in highly reverberant classrooms compared to non-reverberant classrooms when comparing similar classroom activities (Oberdörster & Tiesler 2006). In order to evaluate whether complaints of noise disturbance in the classroom was associated to reduced hearing in schoolteachers, reports from questionnaire to schoolteachers regarding noise disturbance and self-reported hearing loss was followed by test of hearing in 100 schoolteachers from the municipality of Copenhagen.

## METHODS

Teachers in ten schools in the municipality of Copenhagen were invited to participate in the study. Selection and characterization of schools are described below. Out of 419 potential respondents from 10 schools 283 (67.5 %) filled in a questionnaire on health, disturbance by noise, and other work-related items. Of the respondents 89 were men (31 %) and 194 women (69 %), mean age (range) was 45 (21-65) years (men) and 45 (25-66) years (women), respectively. The response rate ranged from

43-89 % from different schools. Self rated hearing loss was addressed in one item "Do you feel you have a hearing loss?" ("Yes" or "No"). Self-rated noise exposure was assessed by an item that read "Are you exposed to noise that disturbs you when you are teaching? ("Never"; "Rarely or very little", "Approximately ¼ of the work time"; "Approximately ½ of the time"; ("Approximately ¾ of the time"; "Nearly always" ). This item is intended to capture the core meaning of noise in the specific occupational context of teaching based on the definition of noise, which is that it is unwanted sounds. The course of the noise was further addressed by questions of the source ("From road-, rail- or air-traffic?"; "From the hallway or other classrooms?"; "From the pupils in the classroom, e.g. talking, chairs rattling, unrest?"; "From ventilation or other machinery?"; "From other sources?") on a scale running from 1 ("Not disturbing") to 7 ("Almost unbearably").

From the 283 respondents, 106 were invited to have their hearing tested. Otoscopic examination was performed before the tests of hearing, and individuals with excessive ear wax were asked to contact their doctor for removal of the ear wax before the hearing test. Overall100 teachers were tested. Distortion product oto-acoustic emissions (DPOAE) were performed bi-aurally with two identical DSP-systems from Tucker-Davis Technologies (TDT, Alchua, FL) and two Ethymotic Research (ER, Elk Grove Village, IL) microphone probe systems (ER10B+ connected by tubes to ER2 sound transducers). The DPOAE assessments on each ear consisted of six DP-grams with measurements of the cubic distortion product (CDP= 2f1-f2) from 32 sets of primary input tones (f2/f2=1.23; f2 ranging from 707 Hz to 10,374 Hz).

The same setup and probe systems was used for assessments of pure-tone hearing thresholds (125.2 Hz; 250.3 Hz; 500.7 Hz; 1,001 Hz; 1,541 Hz; 2,000 Hz; 3,085 Hz; 3,999 Hz; 6,169 Hz; and 7,999 Hz) in 5 dB steps. All tests of hearing were performed in a transportable sound booth (IAC 250 Sound Shelter, complying with ISO 6189). Before measurements of either hearing thresholds or oto-acoustic emissions, proper fitting of the earplugs was tested by measurement of the output from each transducer in situ at 500 Hz.

## RESULTS AND DISCUSSION

In order to compare the results from the tests of hearing to data from questionnaire, hearing thresholds (HT) as well as the oto-acoustic emissions (CDP) was dichotomized by averaging the results across the frequencies of stimulation (PT and f2) from 0.25-1.5 kHz (low frequencies, LH), 2-4 kHz (mid to high frequencies, MF) and > 4 kHz (high frequencies, HF).

The average hearing thresholds was 3.7 dB higher at the mid- to high frequencies in the group reporting to have a hearing loss (13.8 dB ± 1.33 dB; P<0,05) compared to the group reporting normal hearing (10.1 ± 0.9 dB), but HT did not differ statistical significant neither at the low nor at the high frequencies. However, reporting to have a hearing loss was associated with approximately 3 dB at the low frequencies (13.8 ±0.9 dB; P<0.05), as well as the mid- to high frequencies (4.3 ± 0.9 dB; P<0.05), and high frequencies (1.3 ± 1.0 dB; P<0.05) when compared to the participants reporting normal hearing (LF:16.4 ± 0.8 dB; MF: 7.5 ± 0.8 dB; HF: 4.4 ± 1.0 dB).

78 % of the schoolteachers were disturbed by noise more than ¼ of the work time, while only 22 % were rarely or never disturbed. The primary source was quite clearly coming from the classroom, where 71 % of the teachers scored 4 or more on the 7

point scale, which was followed by noise from the hallway or other classrooms with 42 %, traffic noise by 22 % and ventilation noise by 14 % of the teachers scoring 4 or higher.

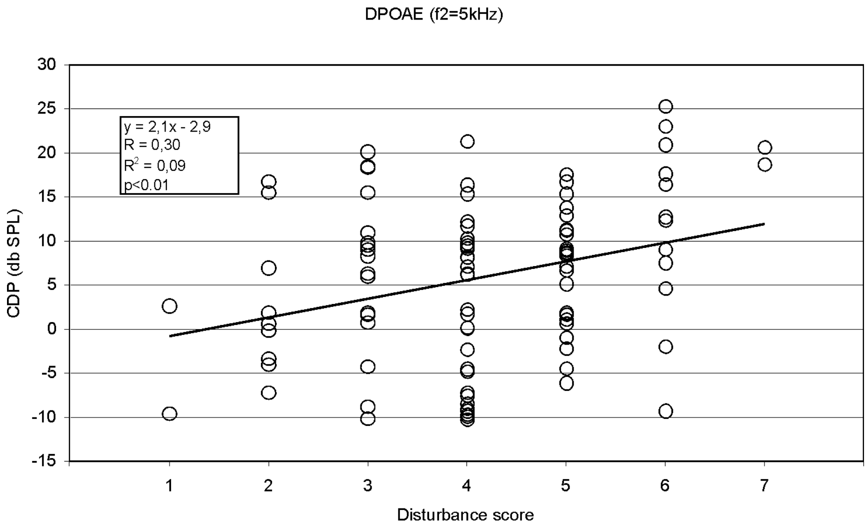


**Figure 1:** Oto-acoustic emissions (CDP) at f2=5 kHz of schoolteachers in association with the degree of disturbance from the classroom, where “Not disturbing” equals 1, and “Almost unbearably” equals 7. Teachers with better hearing (high CDP) are more disturbed by noise coming from the classroom.

There was a statistical significant association between self-reported noise exposure and the degree of disturbance attributed to noise in the classroom, respectively, and measurements of DPOAE. The association is most obvious in the measurements of DPOAE at high frequencies (see Figure.1), and contrary to expectations, higher scores in the disturbance of teaching by noise in the classroom was associated with better hearing (high CDP).

## CONCLUSION

Schoolteachers may seem prone to evaluate their hearing worse than the average citizen, as 45 % rated they had a hearing loss, which could be observed in the measurements of DPOAE, but was not statistically significant different in the measurements of PTA in the group that did not report to have a hearing loss.

There was a statistical significant association between self-reported noise exposure and the degree of disturbance attributed to noise in the classroom, respectively, and measurements of DPOAE at high frequencies, and contrary to expectations higher scores in disturbance of teaching to noise with better hearing. The degree of noise disturbance from sources in the classrooms, and the reality of the perceived noise disturbance of schoolteachers with better hearing may emphasize that noise and poor classroom acoustics is not just a matter of annoyance, but constitute a serious problem in disturbing the processes of teaching.

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# Real-ear attenuation of hearing protection in young children

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## ABSTRACT

Much attention has been focused in the past decade on the possibility that children and adolescents 6-19 years of age may experience noise-induced hearing loss (NIHL) due in part to high-level sound exposure during recreational, hobby, and employment activities. One of the strategies that is utilized to reduce the potential of experiencing NIHL is to wear hearing protection (earplugs and/or earmuffs) when exposed to hazardous noise levels. Currently, many parents rely upon adult-sized hearing protectors for use by their children and even though performance on adults has been measured since the 1950s, the effectiveness of smaller-sized products for children is unknown. This paper examines the feasibility of conducting standardized real-ear-attenuation-at-threshold (REAT) measurements with children of 5–10 years of age, and presents the results achieved with three types of hearing protectors (slow-recovery foam and premolded three-flange earplugs, and earmuffs) measured according to ANSI S12.6-2008. The Method A and B procedures were modified so that rather than the subject (child), the inexperienced parent served as the person inserting the hearing protector. Attenuation metrics are reported in terms of the Noise Reduction Rating (NRR) and 1/3 octave-band attenuation values for each protector. Differences between the three fitting conditions; Trained Parent (Method A), Untrained Parent (Method B) and Expert fit are highlighted. Values are also compared to those found for similar protectors fitted on adults.

## INTRODUCTION

Concern regarding the prevalence of noise-induced hearing loss (NIHL) in U.S. children and adolescents aged 6 to 19 years has been expressed in the past decade (Niskar et al. 2001; Henderson et al. 2011). The World Health Organization has also reported a world-wide concern regarding the risk of NIHL for children (WHO 1997). Evidence of a notched high-frequency hearing loss suggestive of NIHL is not a recent or emerging health concern. In fact, Loch (1943) first described the incidence and permanency of 4-kHz tonal dips in adolescents from Baltimore, Maryland. These studies suggest that hazardous noise exposures from recreational, hobby, and employment activities may contribute to the risk of NIHL in this population.

One of the intervention strategies that is utilized to reduce the potential of experiencing NIHL for both adults and children is to advise the wearing of hearing protection (earplugs and/or earmuffs) when exposed to hazardous noise levels. Hearing protection devices (HPD) are labeled with laboratory-based real-ear-attenuation-at-threshold (REAT) measurements obtained on adults and tested in accordance with U. S. or similar International standards (ANSI S3.19-1974; ANSI, S12.6-2008; ISO 4869-1:1990; ISO 4869-5:2006).

Currently, many parents rely upon adult-sized hearing protectors for use by their children and, even if smaller-sized products are fit, the effectiveness of hearing protectors for children is unknown. Though performance on adults has been measured since the 1950s, there are no standards or guidelines established with respect to laboratory attenuation measurements obtained on young children or adolescents. In clinical practice, it has been generally assumed that the same degree of sound protection is afforded to young ears as compared to adult ears.

This study examines the feasibility of conducting standardized REAT measurements with children of 5–10 years of age, and presents the results achieved with three types of hearing protectors (slow-recovery foam and premolded three-flange earplugs, and earmuffs) measured according to ANSI S12.6-2008.

## STUDY PARTICIPANTS

Human subject participation and consent was obtained after research approval by the Institutional Review Board at the University of Northern Colorado. Child participants ranging in age from 5-10 years were recruited for this study and were accompanied by one parent participant. Child participants were excluded from the study if they exhibited physical features or disabilities, such as those resulting from birth defects, ear surgery, or personal adornments that would adversely affect the fitting of the hearing protectors. Eligible child participants were subsequently screened with otoscopy for earcanals which were free from conditions that would affect the fit of the hearing protector (such as excessive cerumen, irritation, or infection). Acceptance criteria for the child participants included the following; pure-tone air conduction hearing threshold less than or equal to 15 dB HL at the octave-band center frequencies from 125 to 8,000 Hz as measured by a standard audiometer and the ability to understand and speak English and generally follow verbal instructions to ensure study cooperation. Child participants were excluded from the study if 1/3 octave-band thresholds of hearing measured in the sound field of the test room, averaged across two determinations, were more than 3 dB below the octave-band ambient noise levels at any test frequency from 125 to 8,000 Hz.

Adult (parent) participants were over the age of 18 years and also had earcanals free from conditions that would affect the fit of a hearing protector. Parent participants were able to understand, read and speak English. “Inexperienced” parent participants were required to meet the qualifications for inexperience subjects specified in ANSI S12.6 - 2008. All participants received rest periods, nourishment rewards during the rest periods, and monetary rewards upon completion of all test conditions.

## EXPERIMENTAL METHOD

The measurement of REAT is a psychoacoustic test method that relies upon subjective auditory responses from listeners for determining the attenuation of a hearing protector. Auditory thresholds are determined using both an occluded (with hearing protector in place) and unoccluded (without hearing protector in place) test conditions using one-third octave-band noise as the stimulus (ANSI S12.6-2008). Two distinct methods were used in this study for measuring attenuation, Method A: trained-subject fit (which also corresponds to ISO 4869-1:1990), and Method B: inexperienced-subject fit (corresponding to ISO/TS 4869-5:2006). In the U. S., REAT is also be measured via the ANSI S3.19-1974 experimenter-fit procedure as is required for testing to conform to U. S. Environmental Protection Agency hearing protector labeling requirements (EPA 1979).

For this study, REAT testing was sequentially completed with each child participant for three experimental conditions; Method B “inexperienced-subject fit” by an untrained parent, Method A “experienced-subject fit” by a trained parent and “experimenter-subject fit” or expert fit accomplished by the first author who directly fit the child participants. For the untrained-parent condition (Method B), the parent was given the hearing protection device and instructed to follow only the package directions for fitting her/his child with the hearing protector(s). For the trained parent condition (Method A), the parent was given detailed hearing protector fit instructions by the experimenter in accordance with the instructions that were provided with the product. Parents were permitted to fit themselves with the hearing protector to practice their technique. Deviation from the ANSI S12.6 standard Method-A protocol occurred in terms of eliminating the use of fitting noise during parent training due to the lack of auditory feedback to the parent while fitting a child. All participants were fit binaurally.

REAT testing was conducted in a double-walled acoustic test booth. Consistency of head position and orientation was maintained using a plumb bob referenced to the nose of the seated subject. The sound-field test environment was calibrated to ANSI 12.6 and ambient sound levels of the test suite did not exceed those permitted in that same standard. All threshold measurements were obtained using a Grason-Stadler (GSI 61™) audiometer calibrated to ANSI S3.6-2004. The audiometer served as the noise generator with one-third octave band filtering at center frequencies of 125, 250, 500, 1,000, 2,000, 4,000 and 8,000 Hz. Thresholds were measured using a modified Hughson-Westlake test procedure and a 2 dB step size. For each experimental condition, repeat measures of the unoccluded and occluded thresholds were obtained and counter-balanced. Randomization of the hearing protector fitting condition (e.g. untrained parent, trained parent or expert) was not possible due to the influence of one type of training on any subsequent measures.

Three common types of hearing protectors were evaluated; slow-recovery small-sized foam earplugs, youth-sized premolded three-flange earplugs (smaller flanges) and child-sized earmuffs (with standard adult-sized earmuff cups but a smaller headband sized for children’s heads). A new pair of foam earplugs was used for each test condition. New pairs of three-flange earplugs and earmuffs were provided to each child participant and the same HPD was reused for each experimental condition. The experimenter returned the earmuff headband to manufacturer shipping position out of sight of the parent participant between trials.

## ANALYSIS

Threshold data were organized by HPD type and tabulated in an Excel spreadsheet. Descriptive statistics were applied to calculate the means and standard deviations of the REAT data for each octave-band tested and experimental condition; trained parent (Method A), untrained parent (Method B) and expert. The NRR was calculated using the following equation:

$$NRR = 107.9\,dBC - 10\log\sum_{f=125}^{8000} 10^{0.1(L_{Af} - APV_{f98})} - 3\,dB$$

where $L_{Af}$ is the A-weighted octave band level at frequency *f* of a pink noise spectrum with an overall level of 107.9 dBC and $APV_{f98}$ is the mean attenuation value minus two standard deviations at frequency *f* (two standard deviations provides for 98%

protection in a normal distribution) (Franks et al. 1994). The NRR was also calculated with a minus one-standard-deviation correction (providing for 84 % protection in a normal distribution).

## RESULTS

Twenty-six children with a mean age of 8 (and ranging from 5–10 years of age) participated in the study. Fifty-four percent (n=14) were female and reflected the preferred gender balance recommended by ANSI S12.6. All children were able to complete the full study with the exception of one male subject who expressed an aversion to having earplugs inserted into his earcanals. Subsequent discussion with the parent revealed that this subject had a traumatic experience several months prior in which a bee was trapped in his earcanal and stung him repeatedly.

Figures 1-3 reveal the mean and standard deviation one-third octave band attenuation values and calculated NRRs (with both a 2-SD and a 1-SD computation) for each of the three experimental conditions for each hearing protector evaluated. Laboratory data obtained on adult subjects using comparable hearing protectors are also provided for the EPA label test (per ANSI S3.19) and Method B (inexperienced subject-fit). The label test data include attenuation measured at 3 and 6 kHz.

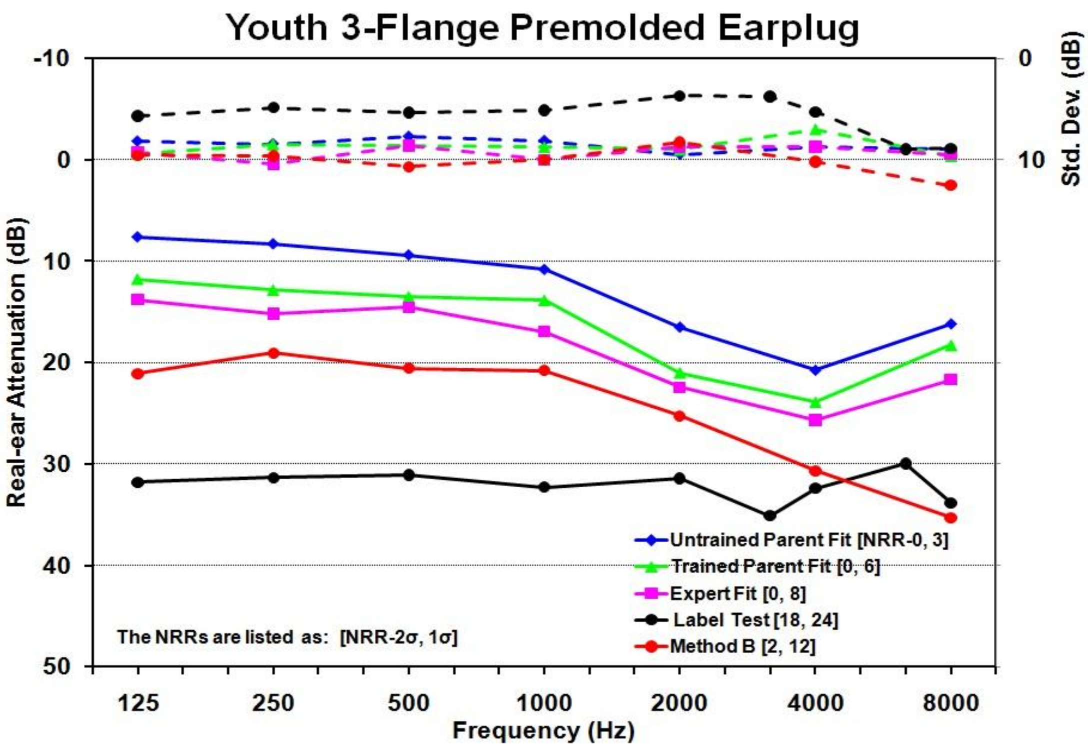


**Figure 1:** Mean attenuation (left axis) and std. dev. (dashed lines, right axis) for children (n-25) fit with 3-flange earplugs and calculated NRRs in brackets with both 2 and 1 standard deviation(s) compared to adult laboratory data

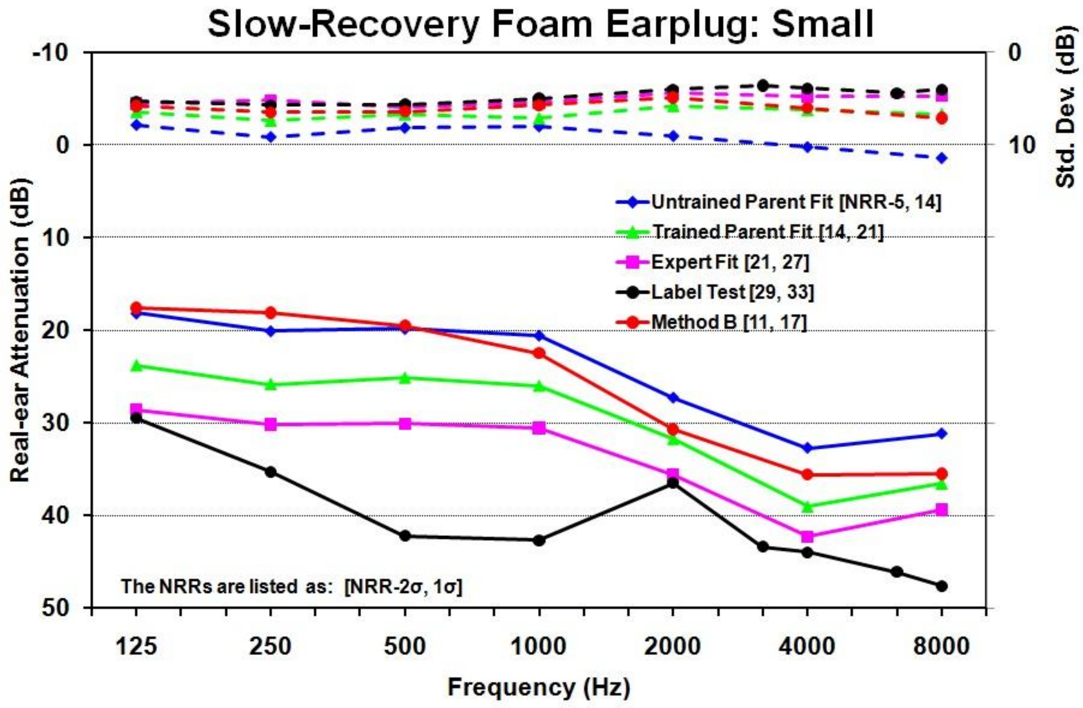


**Figure 2:** Mean attenuation (left axis) and std. dev. (dashed lines, right axis) for children (n-25) fit with slow recovery foam earplugs and calculated NRRs in brackets with both 2 and 1 standard deviation(s) compared to adult laboratory data

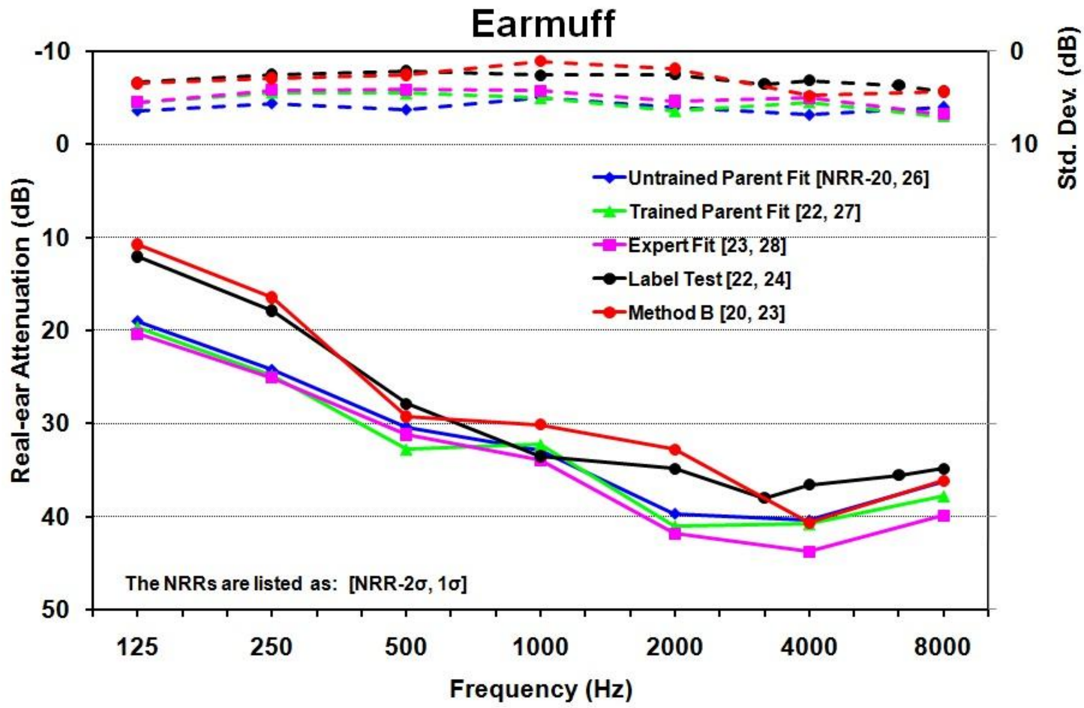


**Figure 3:** Mean attenuation (left axis) and std. dev. (dashed lines, right axis) for children (n-26) fit with child-sized earmuffs and calculated NRRs in brackets with both 2 and 1 standard deviation(s) compared to adult laboratory data with a comparable earmuff

In terms of experimental findings with earplugs, parent training and fitting experience contributes to greater attenuation for children. This is consistent with the training effects reported for adults in the literature (see ANSI S12.6). For both earplug styles evaluated on children, the expert fit provided the greatest degree of attenuation, followed by trained parent (Method A) when compared to untrained parent (Method B). Approximately 5 dB more attenuation was achieved across frequency when parents were trained on the earplug insertion and fitting, however attenuation did not achieve expert-fit levels. For all fitting conditions, attenuation was greater for the 3-flange earplug when measured on adults in the laboratory label test as opposed to children. Variability for the 3-flange earplug attenuation was lowest for adult laboratory label test data and generally consistent across frequency for all other fitting conditions in both children and adults.

The NRRs achieved with slow-recovery foam were higher than those obtained with 3-flange earplugs in children, and it is evident that minimal protection was provided for some children when using the youth-sized flanged earplugs. Interestingly, the slow-recovery foam earplug results for untrained parents (Method B) were essentially identical for 125-1,000 Hz to Method B (inexperienced subject-fit) attenuation measured on adults, though this was not true for the 3-flange earplug. Variability with the slow-recovery foam earplugs was generally comparable for both children and adults with the exception of untrained parents (Method B), especially for the higher frequencies (4 and 8 kHz), where greater variability in excess of 10 dB was evident. Both trained-parent (Method A) and expert-fit testing revealed greater attenuation at all frequencies for children as opposed to adult Method B (inexperienced subject-fit) data. REAT measured in children never approximated adult label-test values for any test frequency when fit with either of the earplugs in this study.

For children, earmuffs generally provide a consistent degree of attenuation regardless of training and fitting experience. In fact, the untrained and trained parent conditions achieved NRRs equal to or exceeding the label-test and Method-B (inexperienced subject-fit) values obtained on adults. Variability was also lower with earmuffs as compared to earplugs; however variability was slightly greater in children than in adults. In our subjects, approximately 10 dB more attenuation was achieved by children than adults for the lowest frequencies (125 and 250 Hz) and approximately 5 dB more attenuation at 2,000 Hz. Parents routinely spontaneously expressed a preference for earmuffs over earplugs in terms of ease of use with children.

## DISCUSSION

REAT testing with children is feasible and reliable. There are challenges when working with this young population in terms of maintaining interest and attention. Providing frequent rest periods and changing the response paradigm from button-pushing to hand-raising to verbal responses to auditory stimuli proved helpful. It was impossible to maintain head position/orientation throughout the testing as the children repositioned themselves in the chair frequently. The examiner was able to call a child’s attention back to the proper orientation through voice-over through the test speakers. For the younger children, visual reinforcement with lighted toys above the test speaker was also useful for re-positioning the head. The examiners will need to be familiar with behavioural audiometry and experienced with pediatric hearing testing paradigms.

Test-retest reliability with children does not appear to be a major concern for REAT measurements. Stuart et al. (1991) reported that the pure-tone test/retest reliability in children does not have a statistically significant difference when compared to the test/retest reliability in adults for behavioral diagnostic testing. These authors state that test/retest reliability becomes a factor when the threshold results obtained are 10 to 15 dB different than previous testing (Stuart et al. 1991) when using a 5 dB step size. The variability for all three types of hearing protection was less than 10 dB and consequently appears to suggest good test/retest reliability for REAT measurements with children.

Relevant to the 3-flange earplug results, the experimenter noted that for the five children who obtained particularly low values of attenuation, the youth-sized flanged earplugs were unable to properly accommodate their earcanals or, in one case, were small enough that even the largest flange could not fully fill and seal the canal. As a result of this, a subsequent experiment is planned to further investigate the fit of an alternative 3-flange earplug on these children. Foam earplugs were routinely not deeply inserted into the earcanals due to very small earcanal apertures; however substantial attenuation was still achieved. It may be inappropriate to judge the adequacy of slow-recovery foam attenuation merely on the basis of visual appearance when worn by children.

Training of parents was felt to be inadequate when referencing the current manufacturer instructions. These instructions were all designed to instruct adults to insert the hearing protector in their own ears and not in a child’s ear. There is a need to modify the instructions to specifically reference the different approaches to insertion necessary with children. Changes to consider include the best direction to manipulate the pinna to expand the aperture of the earcanal, the recommended hand to use for insertion of the earplug, the positioning of the adult in reference to the ear for improved visualization, and the proper insertion technique. Many parents expressed concern that the earplug would harm the child’s eardrum if they inserted it improperly. Therefore, parents also need some anatomical orientation and reassurance regarding this low-risk occurrence. Despite these limitations, training with existing materials does improve the attenuation achieved when parents fit the HPDs.

Children also need training regarding their role in the fitting, auditory and physical expectations and communication with the HPD inserted. It was interesting to note that children often spontaneously reported the occlusion effect after binaural earplug insertions. Children also provided unsolicited verbal feedback to the parent regarding the adequacy of the HPD fit. It may be useful to encourage children to do this if fitting instructions are specifically created for parents and children in the future.

The clinical assumption that HPD attenuation is equivalent between children and adults requires further investigation. The results of this study suggest that earplug attenuation is less than reported for adults and fit training is critical. However, for earmuffs, NRRs are generally equivalent to adult label-test values and, surprisingly, octave-band attenuation values for children exceed adult laboratory values. It may be necessary to consider distinct laboratory testing and labelling for HPDs worn by children. In summary, it is feasible to conduct reliable REAT testing in children to assess the degree of attenuation provided by HPDs in this population and, based on our initial test results with one model of earmuff (with a headband sized for children’s heads) it appears that earmuffs can provide effective levels of protection for children wearing them.

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# Comparison of impulse noise levels generated by a .22 caliber starter pistol and a .22 revolver

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## ABSTRACT

Sports officials commonly use a .22 caliber starter pistol at athletic events to generate a loud impulse sound to signal the start of the event (i.e. race) has started (Figure 1). Acoustic comparisons of the impulses generated from a typical .22 starter caliber pistol (Italian Model 314) firing blank ammunition were made to impulses generated from an actual .22 revolver (Smith & Wesson K-22 Masterpiece) firing both blanks and two types of standard velocity cartridges (.22 caliber short and long rifle ammunition). Peak sound pressure levels at the shooters left ear are higher for the starter pistol than the standard .22 caliber revolver for all types of ammunition evaluated. Hence, a typical starter pistol is not inherently less hazardous to hearing than a traditional firearm and alternative lower-level signaling devices should be considered for sporting events. The use of hearing protection devices (HPDs) by event personnel when firing a starter pistol is recommended.

## INTRODUCTION

Starter pistols are typically designed as revolvers and are fired to start athletic events such as a track and field race, or less commonly, at competitive swimming race. A starter pistol typically has a blocked barrel and fires a charged cartridge (blank) that does not contain a projectile (bullet or shot). The explosive is typically black powder or nitrocellulose. The loud acoustic report of the fired blank cartridge is the auditory signal to which the athletes respond. The “go” shot is fired by the official holding the pistol extended at arm’s length above the head with the barrel angled slightly to the rear. Often a cloth protective sleeve is worn to shield the arm from discharged residue.

**Figure 1:** Track and field event official illustrating starter pistol firing position

In general, handgun weapons firing blanks are presumed to be inherently harmless and are largely unrestricted in terms of sale and carry for adults over the age of 18 years (Giese et al. 2002). However, blank cartridge handguns fired at a close distance are capable of inflicting serious or lethal injury (Jacob et al. 1990; Rothschild &

Vendura 1999; Rothschild et al. 1998; Buyuk et al. 2009). In addition, acute acoustic trauma as a result of impulse noise exposure from weapons firing blanks has been reported (Savolainen & Lehtomäki 1997; Fleischer et al. 2003). In order to prevent noise-induced hearing loss (NIHL) from impulse sounds, the World Health Organization (WHO 1999) recommends a limit of 140 dB peak sound pressure level (SPL) for adults and 120 dB SPL for children.

## STUDY RATIONALE

This study was initiated by an inquiry from a high-school track and field official advocating for the use of electronic starters rather than traditional starter pistols due to the potential risk of hearing loss to the starters and athletes. This official was interested in addressing concern expressed by the director of a State athletic association, and the lack of peer-reviewed evidence indicating that starter pistols are problematic to the student athlete. Specifically, acoustic comparisons of the noise impulses generated from a typical .22 caliber starter pistol firing blanks were made to impulses generated from an actual .22 revolver firing both blanks and two types of standard velocity cartridges (.22 caliber short and long rifle ammunition).

## EXPERIMENTAL METHODS

Two firearms were compared (Figure 2); a typical blocked-barrel .22 starter pistol (Italian Model 314) and an actual .22 revolver (Smith & Wesson K-22 Masterpiece). The .22 starter pistol was fired using .22 Winchester short black powder blank ammunition. The .22 revolver was fired with three types of ammunition; the same .22 Winchester short black powder blank cartridge used in the starter pistol and two bullets; a .22 CCI long rifle and a .22 Winchester short. The bullets are differentiated by their overall length and weight. The CCI long rifle bullet is approximately 2.54 mm long compared to the Winchester short at 17.7 mm. Bullet weights are 40 g and 29 g for the CCI long rifle and 29 g for the Winchester shorts. Five shots were fired for each of the four firearm/ammunition combinations.

**Figure 2:** .22 Italian Model 314 blocked-barrel starter pistol (left)
a .22 Smith & Wesson K-22 Masterpiece revolver (right)

Impulse recordings were made using ⅛ inch prepolarized pressure calibrated microphones (G.R.A.S. Type 40DP) oriented at grazing incidence to the sound source. Microphone output was conditioned with ¼ inch preamplifiers (G.R.A.S. Type 26AC) driven by a constant voltage power module (G.R.A.S. type 12AA) and routed to a National Instruments PXI-6120 with a simultaneous sampling data acquistion board mounted in a four slot PXI chassis for A/D conversion. This board allowed simultaneous 4-channel data recording with 800 kHz sampling rate and was stored in a

64 Msample on-board data buffer that was set-up to record 50 ms of data before the trigger with a total recording duration of 0.5 s. The data were sampled with16 bit resolution, giving a 90-dB dynamic range and scaled into Pascal (Pa) units. The data acquisition process was controlled by a custom LabView program with integrated calibration routine and trigger control. The data were post-processed in National Instruments Diadem software with subequent transfer into MATLAB software routines originally developed in the NIOSH Taft Laboratories (Cincinnati, OH). Peak sound pressure levels were calculated.

Near-field measurements were made by positioning the microphones on stands at specific locations relative to the firearm or shooter as illustrated in Figure 3. Testing was performed outside on a grass surface with no other major surfaces creating reflections within the time period of interest.


**Figure 3:** Microphone locations; A) 1.5 meters in front ofmuzzle, B) left of muzzle, C) left of chamber/cylinder and D) shooter's left ear with 5 cm offset from the skull. All other offsets were 10 cm left of the barrel.

RESULTS

Sound pressure levels at the shooter's ear are most relevant in terms of risk of acute acoustic trauma. For comparative purposes, the composite waveforms of the 5 shots recorded at the shooter's left ear microphone (Fig. 3D) are presented in Figure 4 (A-D). All waveforms are represented on a common pressure scale (maximum 4000 Pa.) to simplify comparison. The .22 starter pistol shooting blanks generated the highest peak pressure at 3692 Pa or approximately 165 dB peak SPL (Fig. 4A) and the .22 K-22 Masterpiece revolver firing the same blank cartridge had the lowest peak pressure at 491 Pa or approximately 148 dB peak SPL (Fig. 4C). Peak pressures ranged from 1143-1604 Pa (≈155-158 dB peak SPL) when bullets were fired from the .22 revolver.

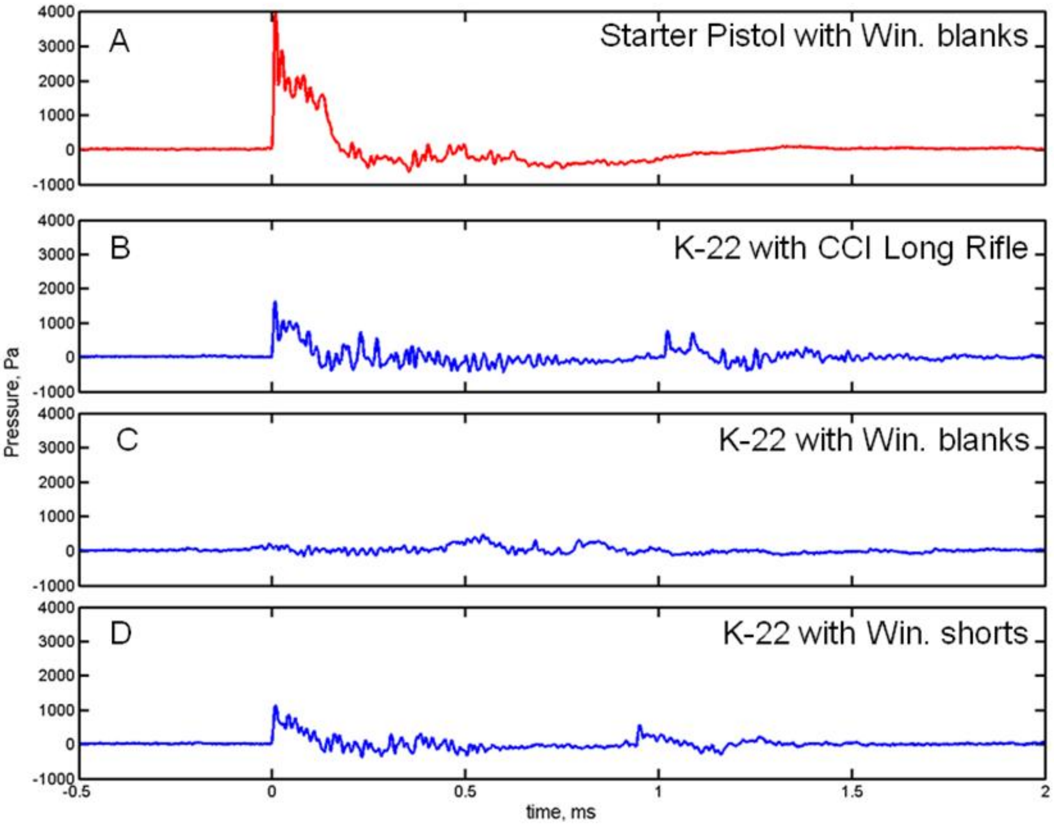


**Figure 4:** Composite waveforms recorded from the shooter's left ear microphone equally scaled to 4000 Pa. for each condition

The peak SPL measured at the chamber/cylinder microphone was 21.6 dB higher for the .22 starter pistol shooting blanks than for the .22 K-22 Masterpiece revolver firing the same blank ammunition (Table 1). The blocked barrel design of the .22 starter pistol may contribute to this substantial difference since the explosive gases are forced to exit at the chamber/cylinder openings and are unable to travel down the barrel and escape at a greater distance from the shooter's ears. The SPLs measured at the chamber/cylinder microphone for the .22 starter pistol shooting blanks were comparable to the levels obtained when the bullets (long rifle and shorts) were fired using the K-22 Masterpiece revolver.

At a position 1.5 meters in front of the muzzle, peak SPLs generated by the pistol or revolver are approximately 3-5 dB higher for blank cartridges than for the .22 CCI long rifle and Winchester shorts. At the muzzle microphone position, SPLs ranged 2.0 to 4.8 dB higher for blank ammunition fired in the .22 starter pistol when compared to levels from the K-22 Masterpiece.

**Table 1:** Summary comparison of peak pressure (Pa) and sound pressure levels (SPL)

| Firearm and Ammunition | Shooter's Left Ear Mic | Chamber / Cylinder Mic | Muzzle Mic | 1.5 m. In front of muzzle Mic | Units |
|---|---|---|---|---|---|
| .22 caliber Italian Model 314 Starter Pistol Win. Blanks | **3692.2** | 18898.8 | 14037.6 | 1494.6 | Pa |
| .22 caliber K-22 Masterpiece Revolver CCI Long Rifle | 1603.9 | 21784.4 | 11115.6 | 1002.6 | Pa |
| .22 caliber K-22 Masterpiece Revolver Win. Blanks | 490.9 | 1574.2 | 9999.0 | 1814.4 | Pa |
| .22 caliber K-22 Materpiece Revolver Win. Shorts | 1142.9 | 14273.8 | 8009.0 | 1089.2 | Pa |
| | | | | | |
| .22 caliber Italian Model 314 Starter Pistol Win. Blanks | **165.3** | 179.5 | 176.9 | 157.5 | dB SPL |
| .22 caliber K-22 Masterpiece Revolver CCI Long Rifle | 158.1 | 180.7 | 174.9 | 154.0 | dB SPL |
| .22 caliber K-22 Massterpiece Revolver Win. Blanks | 147.8 | 157.9 | 174.0 | 159.2 | dB SPL |
| .22 caliber K-22 Masterpiece Revolver Win. Shorts | 155.1 | 177.1 | 172.1 | 154.7 | dB SPL |

## DISCUSSION

All SPLs measured for blank cartridges exceeded 140 dB SPL and put the shooter at risk of acute acoustic trauma. When athletic officials raise the starter pistol towards their ears, above their heads and angled backwards, they actually orient the cylinder/chamber towards the ear. Additionally, it is counterintuitive to consider that lower sound-levels occur with weapons firing .22 caliber projectiles when compared to .22 blank cartridges. In terms of risk of acoustic injury, the general assumption that starter pistols are "safer" is erroneous.

The USA Track and Field National Track and Field Officials Committee has published a monograph series on the mechanics and techniques of track and field officiating. The monograph entitled "Starters" (Zemper 2010) specifically recommends three strategies for the prevention of hearing loss. First, officials starting track and field events are advised to wear hearing protection in both ears (p 29), yet the protection should not impair audibility necessary for communication during the event. Second, it suggested that using an open barrel pistol offers another strategy for officials to consider in terms of preventing blast injury to the ear. This approach is tempered by the need to obtain a weapons permit from the appropriate law enforcement agency and compliance with rules requiring the use of close-barrel starter pistols at high school events. Third, new electronic starting pistols are suggested as a possible, less hazardous, alternative to starter pistols fired with blank cartridges. Some resistance to the newer electronic starters arises from the increased cost to implement the devices and the difference in the acoustic signal which is reported to be less sharp and intense for the athlete. The loudness level of the starter pistol has been shown to provide an advantage in terms of reaction time for the runners closest to the starter at the Olympics (Brown et al. 2008) and concern may be warranted.

The challenge for sport officials will be to find hearing protectors that provide adequate attenuation and also provide audibility when worn during sporting events. Electronic or non-linear attenuation devices may be appropriate for these individuals. Certainly education regarding the need for bilateral protection is also necessary since many officials compromise for communication purposes by wearing an earplug in the ear closest to the pistol and leave the opposite ear unprotected in order to communicate.

Considerations for athlete noise exposure can be extrapolated, even though no direct measures were completed for this study. Applying the inverse square law using the 165 dB SPL value obtained at the starter's ear; peak SPLs for a track and field athlete lane position would be the following; 159 dB SPL at 1 m, 153 dB at 2 m, 147 at 4 m etc. If the most distant lane position is 14 m from the starter, a peak SPL of 136 dB would be possible. This level of impulse noise exposure would exceed the WHO recommended limit of 120 dB SPL for youth. Further investigation is planned to explore this possibility in an actual track and field acoustic environment.

## SUMMARY

At the shooter's ear, a blocked barrel .22 caliber starter pistol produces higher (7-18 dB) SPLs than a comparable actual .22 caliber revolver, regardless of ammunition type. Shooters are advised to utilize hearing protection devices (earplugs and/or earmuffs) when firing starter pistols at athletic events.

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# Evaluation of awareness of noise-induced hearing loss among South African soccer spectators

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## ABSTRACT

South African Premier Soccer League matches have recently come under spotlight as recreational activities with potentially hazardous noise levels. While much is known about the noise levels during some of these matches, little is known about the awareness and perceptions of the spectators regarding the risks posed by noise during these matches. This study will evaluate the awareness of noise-induced hearing loss (NIHL) among South African soccer spectators, determine their patterns of exposure to loud noises and their attitude towards hearing protection use. A descriptive quantitative cross-sectional study, using a 24-question, self-administered questionnaire was used. Eighty-two soccer spectators (47 males and 35 females), selected via convenience sampling before the start of a match completed the questionnaire. About half of the respondents 48 % [CI: 36.3, 59.9 %] reported being aware that the noise they were exposed to during soccer matches could potentially be harmful to their hearing. Eighty-seven percent (87 %) [CI: 76.6, 93.4 %] of them did not consider noise-induced hearing loss to be "a very big problem" when compared to other health concerns such as drug and alcohol abuse. Most respondents in this study were not aware of the potential harm of noise to their hearing and most also did not consider hearing loss from noise exposure during soccer matches to be a serious health concern.

**Keywords:** Noise-induced hearing loss, soccer, spectators, awareness

## INTRODUCTION

Hearing loss due to exposure to excessively loud noises is a significant social and public health concern (Chung et al. 2005) and noise exposure will continue to be a major public health problem in the 21$^{st}$ century (Passchier-Vermeer & Passchier 2000). Subsequently, this implies that Noise-Induced Hearing Loss (NIHL) is also likely to continue to be a challenge. The World Health Organization (WHO) has also identified noise-induced hearing loss in developing countries an increasing risk factor for hearing impairment (WHO 1997).

Soccer is one of South Africa's favorite sports and it draws an enormous amount of spectator enthusiasts. However, South African Premiere Soccer League (PSL) matches are known to be some of the noisiest social events. The biggest contributor to noise levels during matches is the *'vuvuzela'*, a trumpet-like instrument that is usually blown by South African soccer lovers at matches (Swanepoel & Hall III 2010). Peak sound levels at some of the PSL matches are in the ranges 115-132 dBA, with average sound levels ranging from 85.3-92.7 dBA (Ramma et al. 2011). These are sound levels that are harmful to human hearing if people are exposed to them for extended durations (ISO 1999).

There have been intense complaints by the general public about the level of noise at soccer matches. Some people have gone to the extent of calling for the banning of the vuvuzela from soccer matches to reduce excessive noise exposure during matches (Staff Writer 2009). Certain researchers have also called for heightening campaigns to promote public awareness and education about the NIHL at soccer matches (Swanepoel & Hall III 2010). However, before calling for an increase in public awareness campaigns, an attempt should be made to try and understand factors that influence the spectators to behave in a certain manner. In other words, influence for behavior modifications may be achieved more effectively if soccer spectators' perceptions about hearing and NIHL are first understood.[1] Some of the questions that may be asked include: Generally, what do South African soccer spectators know about hearing loss, more specifically, NIHL? What are their views regarding the use of hearing protection, and which strategies could be used to influence preventative behaviors (Chung et al. 2005)?

This study will attempt to answer some of the above stated questions. The objectives of this study were therefore to: 1). Evaluate the awareness of NIHL among South African soccer spectators, 2). Determine their patterns of exposure to loud noises and 3) Determine their attitude towards hearing protections.

RESEARCH METHOD AND DESIGN

This was a descriptive cross-sectional survey study. Before the survey was conducted, ethical clearance was first obtained from the University of Cape Town Faculty of Health Sciences Human Research Ethics Committee (REC REF: 373/2009). Permission was then obtained from the stadium management. The questionnaire used (with permission) in this study was developed at Massachussets Eye and Ear Infirmary, Harvard School of Public Health, and Congent Research, Inc., Chung et al. 2005).

The questionnaire was first adapted and piloted on 10 individuals prior to the commencement of the survey to make it suitable for use in a South African context on the target population for this study. It contained 4 sections; the first section of the questionnaire contained five questions about views towards general health issues relevant to soccer spectators (including hearing loss). The remaining three sections dealt with the following areas; hearing loss, personal exposure to loud noises (specifically vuvuzela noise) and hearing protection. The format of the questions in the questionnaire included multi-dichotomous, multiple choice and open-ended questions.

**Study population**

Soccer spectators attending a PSL cup-final match (May 22, 2010) at the official opening of a 96 000 seat-capacity flagship stadium for the FIFA 2010 soccer world cup tournament were sampled via convenience sampling to participate in this study. Eighty-two soccer spectators (47 males and 35 females), age range 18-61 years old (median age 30 years old) completed the questionnaire for the study. Nine of the completed questionnaires had to be discarded because they had the required biographical data missing. The remaining questionnaires (n=73); 41 males and 32 females, were analyzed and demographic information of the respondents is presented in Table 1:

**Table 1:** Demographic profile of the respondents (n=73)

| | ***Respondent ( %)*** |
|---|---|
| ***Gender:*** | |
| *Male* | *56* |
| *Female* | *44* |
| ***Age:*** | |
| *20-30** | *53* |
| *31-40* | *25* |
| *> 40** | *17* |
| ***Education:*** | |
| *Secondary†* | *47* |
| *Tertiary* | *32* |
| *Postgraduate* | *20* |
| ***Employment status:*** | |
| *Employed* | *75* |
| *Unemployed* | *25* |
| ***Matches attended*** | |
| ***(past 12 months):*** | *47* |
| *<10* | *33* |
| *10-20* | *20* |
| *>20* | |

*Respondents <20 years and >60 yrs made up 5 % of the sample
†Respondents with primary education made up <2 % of the sample

## Data collection

Data collection took place on the above stated date between 11 a.m. and 2 p.m. (until 1 hour before commencement of the match). Two research assistants waited at two of the many stadium entrances and approached football spectators as they entered the stadium. Football Spectators were surveyed as they went into the stadium to avoid surveying the same individuals multiple times. The researcher was available to answer any question about the study or the questionnaire that the respondent may had.

## Data analysis

Both descriptive and inferential statistics were used to analyze the results of the study. Pie-charts and percentages (with 95% confidence intervals [CI]) were used to display patterns of responses. Pearson Chi-square ($X^2$) was used to infer associations between different variables.

RESULTS

## Awareness about HL

Forty-eight percent 48 % [CI: 36.3, 59.9 %] of the respondents in this study reported that they knew that the noise made by blowing the vuvuzela can damage their hearing. Hearing loss due to too much noise during matches was considered to be “a very big problem” by 13 % [CI: 6.4, 24.0 %] of the respondents. Drug and alcohol abuse during football matches was considered to be “a very big problem” by 44 %, [32.6, 56.6 %] of the respondents, followed by cigarette smoking in stadium stands (40 %)[CI: 28.7, 52.4 %], acts of violence (e.g. fights in the stands) (38 %)[CI: 26.6, 49.7 %] and risk of catching airborne infectious diseases such as flu or tuberculosis (TB) at soccer matches (18 %)[CI: 10.5, 29.6 %]. Females were more likely to rate hearing loss from too much noise during matches to be “a problem” or “a very big problem” than males (p=0.042).

Fourteen percent (14 %) [CI: 6.8, 24.8 %] of the respondents reported experiencing some hearing-related problem after attending a football match. The most frequent hearing related problem reported was ‘temporary hearing problem.’ Figure 1 below shows how respondents rated hearing loss from too much noise during matches.

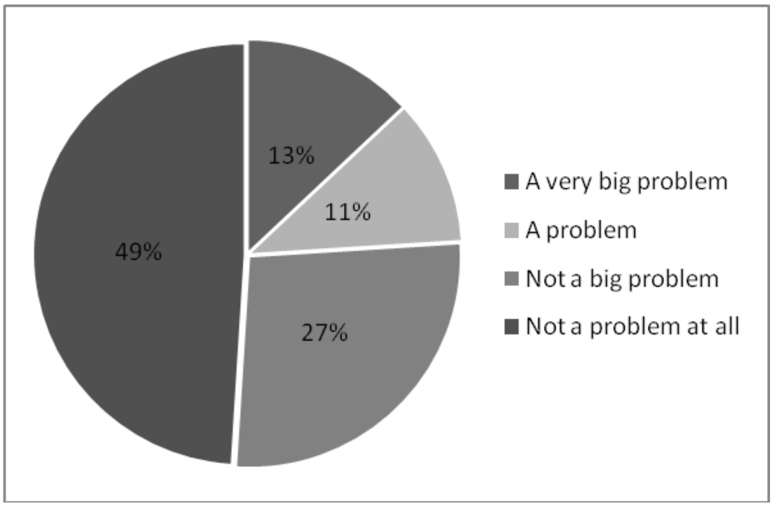


**Figure 1:** Respondent’s rating of hearing loss from too much noise at matches (n=73)

## Patterns of noise exposure

Seventy-five percent [CI: 63.6, 84.4 %] of the respondents reported owning a vuvuzela and using or blowing it at all matches they attend. In response to the question; “Now that you know that the noise made by the vuvuzela can damage your hearing, are you going to stop blowing it during matches?” 76 % [CI: 63.3, 86.0 %] of the respondents answered “NO” and 60 % [CI: 44.4, 73.9 %] of those who responded “NO” said that they will not stop blowing the vuvuzela because it is ‘part of South African soccer culture’ and 38 % [CI: 26.1, 55.3 %] reported that it ‘makes the game more fun to watch.’ Eighty-eight percent [CI: 77.3, 94.3 %] of all the respondents did not want the vuvuzela to be banned during soccer matches.

## Attitudes toward hearing protection

Eight percent [CI: 2.9, 17.8 %] of the respondents reported that they have worn earplugs during a football match while 22 % [CI: 13.1, 33.6 %] of them reported that they have seen someone wearing hearing protection devices at a football match. Twenty-nine percent [CI: 18.7, 40.8 %] of the respondents said that they were “very likely” to use ear plugs during matches if they were provided for free at the stadium. However, 40 % [CI: 28.7, 52.4 %] of the respondents said that they were “not at all likely” to use ear plugs during matches even if they were provided for free. Twenty-two [CI: 12.7, 33.8 %] of the respondents reported that they were “very likely” to use ear plugs next time when they attend a match. Forty-five percent [CI: 32.5, 57.4 %] of the respondents reported that they did not know where they could buy earplugs.

## DISCUSSION

Despite widespread concerns that have been expressed mostly in the mainstream media about excessively high noise levels during most of PSL matches, the findings of this study revealed that soccer spectators who took part in it considered the risk of a hearing loss from too much noise during matches to be a low health concern when compared to other health concerns (e.g. people smoking in the stands). This was a further confirmation that hearing loss was considered a health concern of low priority amongst these respondents. The findings of this study are consistent with those of previous studies which suggest that unlike health concerns such as drug and alcohol abuse and acts of violence, which may have immediate life-threatening consequences, noise-induced hearing loss takes longer to show, therefore most people tend to rate it as a lower health concern (Chung et al. 2005; Berger 2001).

Only 14 % of the respondents reported experiencing temporary hearing difficulty or tinnitus after attending a soccer match. This is a relatively low proportion than expected, especially when considering high noise levels that have been recorded at some PSL matches (Ramma et al. 2011). This may assist further in explaining why majority of soccer spectators rated hearing loss as a low priority health concern amongst soccer fans. The number of people who reported hearing related problems in this study was low when compared to the number reported in a similar study of people exposed to leisure noise. For instance, in a study by Chung et al. (2005), 61 % and 43 % of the respondents reported experiencing tinnitus and hearing loss respectively after exposure to loud leisure noise.

Only 8 % of the respondents reported ever using hearing protection when attending a soccer match and 22 % of them said that they have seen someone using hearing protection at soccer matches. Low use of hearing protection was not surprising because most people do not like using them. Even in an occupational setting where use of hearing protection is legislated and enforced, employers battle to get the employees to comply with hearing protection use (Arezes & Miguel 2002).

Despite limited contact during this survey between the researchers and respondents, it was encouraging to note that 22 % of the respondents indicated an intention to use hearing protection when attending their next match. This suggests that behavior change towards noise exposure could potentially be facilitated through focused public education on hearing conservation. Effectiveness and positive impact of hearing conservation programs in a non-occupational setting have been reported in some studies (Griest et al. 2007; Luke & Johnson 1999).

## CONCLUSION

Majority of South African match spectators who participated in this study did not consider hearing loss to be a major health risk facing people who attend soccer matches. Most of the respondents expose themselves to noise levels that are potentially harmful to their hearing, and most indicated some resistance towards stopping the use of the vuvuzela, a known noise pollutant at soccer matches. However, willingness to use hearing protection was demonstrated, if it were provided at no cost. Even more encouraging was respondents' reports of increased likelihood of using hearing protection if that suggestion came from a doctor or a nurse.

## ACKNOWLEDGEMENT

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# From ISO 1999 to noise policy

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## INTRODUCTON

Noise pollution is a pervasive byproduct of industry and densely populated regions, impacting the quality of life, both socially and medically (Alberti 1998). Almost 25 % of Europe's population is exposed to transportation noise exceeding 65 dBA, determined as 24 h average energy equivalent noise. In some countries more than one half of the population is exposed to transportation noise (Hinchcliffe 1998). When environmental noise exceeds 65 dBA, sleeping is disturbed and the quality of waking hours compromised. Levels exceeding 85 dBA can cause hearing loss. Both in the United States and Europe, 30 million people are exposed to potentially hazardous levels of noise. Approximately 400 to 500 million people are at risk of developing noise-induced hearing loss (NIHL) (Alberti 1998).

NIHL is considered to be one of the most common occupational health hazards of any country. There are no global figures available for the prevalence of NIHL. Such figures, if they did exist, would lack validity in a rapidly changing industrialized world (Alberti 1998).

When NIHL is moderate to severe, it leads to speech distortion, reduced word discrimination, increased noise intolerance and tinnitus. Reduced oral communication is a social handicap (Ward 1986). NIHL also reduces the perception of warning signals, environmental sounds and music. Consequently, NIHL may lead to social isolation, decreased worker productivity and morale, and an increase of job-related accidents (Ward 1986).

The International Organization for Standardization (ISO) published in 1975 a standard for assessing occupational noise exposure for hearing conservation (ISO 1999 (1975)). The version was updated in 1990 The ISO-model (ISO 1999 (1990)) uses three input parameters: age, exposure to noise, and gender in the evaluation of NIHL. Exposure to noise is evaluated using the equal energy principle. Based on these parameters the distribution of NIHL can be calculated. The variation is large; for men the difference between 10 % and 90 % percentile of hearing loss is 60 dB when the subjects are exposed to a noise level of 100 dBA for 30 years. According to the ISO-model women are somewhat less vulnerable to noise than men. The large variation has been explained by several factors like pitfalls in the equal energy principle, other noise exposure, confounding biological and environmental factors and individual susceptibility factors (Borg 1992; Campo & Lataye 1992; Pyykkö et al. 1988).

According to ISO 1990 there are two components responsible for the deterioration of hearing: the age related component and noise exposure related component. According to the standard the age related component (presbyacusis) is more important than the noise exposure related component until the daily exposure is 90-95 dB. In the standard these components are additive, which suggests that people that are susceptible to noise have an increased risk of hearing loss even without noise exposure.

The ISO 1999 (1990) predicts the distribution of audiometric results in large populations. Audiometry is the gold standard in the evaluation of hearing loss. However the correlation of the audiogram with subjective evaluation and handicap varies between 0.2 and 0.5 (Barrenäs & Holgers 2000). There is no prediction model to other hearing symptoms like tinnitus. Its prevalence is not correlated to audiograms (Toppila et al. 2011).

Nevertheless poor audiometric results indicate problems with hearing (Sataloff & Sataloff 1993). In Finland less than 10 % of the workforce is working in conditions where the noise exposure exceeds 85 dB. Provided that the ISO 1990 model is generally applicable, the number of working people with hearing handicap due to presbyacusis is greater than the number of working people having hearing loss due to noise-induced hearing loss. Thus to reduce the number of people with hearing handicap it is necessary to reduce the impact of presbyacusis component in the ISO 1999-model.

The presbyacusis component is due to genetic factors and lifestyle factors (Nosocusis). This is why the presbyacusis component can be reduced. For example musicians (Toppila et al. 2011) and army pilots (Kuronen et al. 2004) have smaller presbyacusis component and smaller susceptibility to noise than ISO 1999 predicts.

Factors affecting presbyacusis and noise susceptibility are as follows:

1: Diseases

The following diseases are correlating with hearing loss (Pyykkö et al. 2007)

- Otitis in childhood (at least 3 attacks)

– Otitis as adult (at least 3 during the last year)

– Chronic Otitis (duration over 3 kk)

2: Nosocusis

It has been shown that elevated cholesterol, elevated blood pressure, use of painkillers and smoking increase the probability of hearing loss ((Toppila et al. 2000, 2001; Starck et al. 1999). When several of these factors exist the may mask the effect of noise completely (Toppila et al. 2001; Pyykkö et al. 1989). The effect of single factor may be small but in combination it becomes visible (Toppila et al. 2001; Pyykkö et al. 2007). The most important single factor is the young age cholesterol with risk ratio 7.2 (Pyykkö et al. 2007).

In addition there are other factors like skin pigmentation (Barrenäs 1998; Royster et al. 1980) may have an effect to noise susceptibility. Also mandatory military service causes hearing losses in Finland (Savolainen & Lehtomäki 1996).

Provided that the presbyacusis component can be reduced the probability of hearing loss can be reduced by 30 %.

The European legislation recognizes as the only means the reduction of noise exposure. This can be done by reducing the noise levels at workplace with technical means or by using hearing protective device (HPD). Several authors have questioned the efficiency of the HPDs based on the field attenuation results (Berger 1983; Casali et al. 1991). Maybe the most important factor is the poor usage rate. Toppila et al. (2005) found that the percentage of always users varied between 30 % - 95 % in shipyard, forestry and paper mill industry. The lowest percentage was found in paper mills where the noise levels were the lowest ones. This indicates that reduction of noise level in work may even increase the prevalence of noise induced hearing loss if the usage rate decreases faster than the noise exposure. Morata et al. (2005) have studied why HPDs are not used. The HPDs makes difficult to hear what is happening. This is especially true for workers with hearing handicap.

## THE IMPACT OF NOISE ON SOCIETY

Although noise induced hearing loss (NIHL) is the most common occupational disease, it seems to have no major impact to the society. There are no sick-leaves and very few work disability cases due to hearing loss (HL). The reason for this contradicting result is that HL has an impact on other things like:

1. unemployment
2. mental symptoms like depression
3. increased accident risk.

When recording these things, the HL is seldomly mentioned in the statistics.

We live in a communication society. Today over 80 % of workers need communication skills at their work. This is true also for work in noisy environment. Hearing handicap causes communication in background noise difficult. Thus working in the factory floor or in open offices may become difficult and eventually a cause of long-term unemployment. In a Danish study (The Danish Institute for Social Research, 2003) the unemployment of those with hearing handicap is four time higher than those with normal hearing.

In daily communication subjects HL experience disabilities in communication when they are facing less than ideal conditions, for example, on a phone, varying levels of background noise, reverberant rooms, and in group conversations (Hallberg & Barrenäs 1993; Hétu et al. 1993). Because the onset of hearing loss is deceptive, people tend to avoid these disabling situations. In the long run this avoidance process results in changes in the lifestyle of people with hearing impairment (Hallberg & Carlsson 1991). The resulting handicap caused by HL affects the social and family life in different ways. The partner of a person with HL needs to pay attention when communicating with the impaired family member. The verbal contact should be performed under visual conditions and the information content must be confirmed. The handicap affects the unimpaired family member by forcing them to keep the conversions brief. Other consequences may include setting higher volumes when watching television or listening to music, loud speech and the increased social dependence of the impaired partner (Hétu et al. 1993).

These factors become more and more important as the working force is getting older. In USA the Bureau of Labor Statistics projects that there will be 40 million workers over the age of 55 by 2018 (Toossi 2009). By this time, workers aged over 45 are projected to constitute almost 45 % of the total workforce. One-third of workers aged 65 and older reported trouble with their hearing in the National Health Interview Survey 1997-2004) - three times the number reporting visual impairment (Davila et al. 2009). In these circumstances, it will become increasingly difficult for older workers to find jobs if their performance does not match that of younger workers.

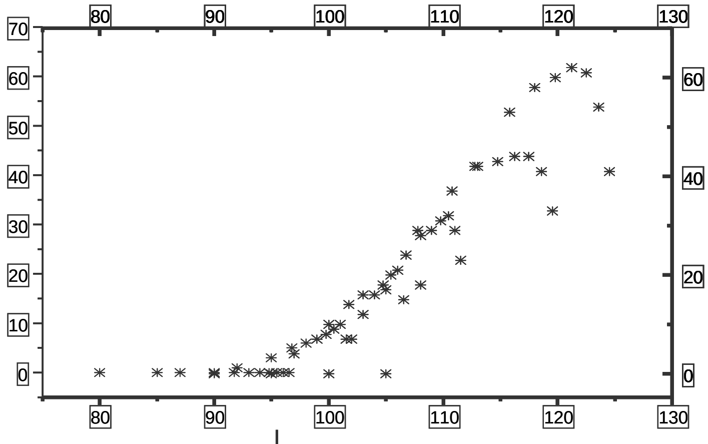


**Figure 1:** The probability of hearing loss according to ISO 1999 (1975) with Lex=80-110 dB. Y-axis= probability X-axis lifetime exposure

The impact of noise to accident risk is not well understood. In Canada Deshaies et al. (2008) have estimated that in 3 % of all accident noise has had a major impact the accident. It seems the workers with hearing handicap are more susceptible to accidents because misunderstandings, missing warning signal and reduced sound localisation capabilities(Toppila et al, 2009b). Accident statistics in Finland show 2-4 cases in 10 years where noise is a contributing factor to the accident.

In Sweden 32 % in working population has hearing problems (hearing loss and/or tinnitus) (Hasson et al. 2011). These symptoms are associated with stress. In Finland we could demonstrate that self-evaluated hearing problems correlates with decrease of quality of life (Toppila et al. 2008). In this study 15-25 % of workers using communication device reported difficulties at work due to hearing. About 10 % of the working population has a hearing loss. Only 20 % of these cases are related to occupational noise exposure.

Workers with hearing loss seem to disappear from the work force. This is seen from the model of ISO 1999 (1975) (Figure 1.) where the probability of HL decreases when the exposure exceeds a limit. This may be due to the fact that workers with HL have problems to do their work properly. Also people think that they are stupid. A moderate effect to mental health among young and middle aged workers has been reported (Tambs 2004).

This justifies making a model where people with hearing loss have an increased risk of early removal from the work force (Figure 2). As this removal happens through unemployment, accident and mental problems there is seldom notification about the HL which is at least a contributing factor to the removal.

In Figure 2 are given some estimated figures how removal from workforce can occur. Early retirement refers to cases where poor hearing causes stress, or difficulties at work, which makes the subject willing to retire as soon as possible. In the lower right corner are some estimates about the statistics. Applying the ISO 1999 (1990) model to the Finnish criteria of Noise Induced Hearing Loss, it can be estimated that the number is 30 % too high. On the other hand only for half of the people with non-occupational HL there are data available about audiogram. This data is never transferred to the cause of retirement or unemployment.

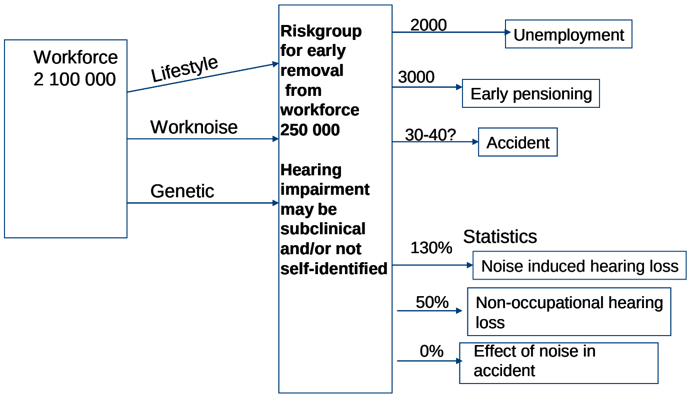


**Figure 2:** Causes of hearing loss, removal from the active workforce and official statistics

## DISCUSSION

In this paper we have examined environmental factors affecting to hearing and the impact of hearing loss in work life. Noise causes hearing loss but also it makes the life difficult to those with hearing loss. Pejtersen et al. (2011) have shown that in open offices there are 62 % more absences than in traditional offices. Noise, ventilation and spreading of infection are the most probable explanations according to the study. If this is true noise can cause sick leaves, but still they do not show up in the statistics as noise induced sick leaves. The same problem applies to early retirement where noise and/or hearing loss are involved. We may only estimate the order of magnitude of the problem.

The fight against HL must be started early. Ear infections in the kindergarten is the first point where an intervention can be made by vaccination. This has started in Finland in 2010. Next interventions should be started when people are in the age of 12-15 years. At this age correct attitudes towards hearing protection are easy to develop (www.dangerousdecibels.org). Also this is the time to have an impact to the free-time noise exposure and the best time to promote healthy lifestyle, which prevents nosocusis.

For working people there are three possibilities

- hearing protection for noisy workplaces
- workplace design to take into account HL
- improving personal solutions for people with mild HL.

Only the first possibility is mandatory by law. For workplace design there exist good methods, but maybe the need is not fully understood. At workplaces where communication needs are complex, the personal solutions should be developed even for people with subclinical HL. There is a performance limitation of hearing aids and the social stigma associated with their use, particularly for workers with mild hearing loss characteristic of that associated with aging (Kochkin 2007).

Finally something should be done to understand the relationship between HL, unemployment and mental disorders. However this seems to be the most difficult part. The protection of privacy makes it almost impossible.

## CONCLUSIONS

Noise is an underestimated problem in our society. Modern work sets needs for communication even in difficult conditions like factory floors and open offices. Background noise is not regarded as a health hazard because there are no good ways to evaluate its effects. The background noise seems to be difficult especially for those with hearing impairment. Nowadays only the effects of noise to hearing are evaluated. A much broader approach, which includes the effect to communication and other health effects, is needed.

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# Increased DPOAE levels following high level noise exposure: a case study using DPOAE level/phase mapping

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## ABSTRACT

Distortion product otoacoustic emission (DPOAE) testing shows promise for detecting noise-induced hearing loss early and monitoring cochlear status. A reduction in DPOAE levels is commonly associated with cochlear damage from hazardous noise; however, some studies have reported sporadic instances of increased DPOAE levels in noise exposed subjects. We studied one such normal hearing individual before and after exposure to hazardous occupational noise (400 % noise dose) using a series of DPOAE level/phase (LP) maps based upon techniques first reported by Knight & Kemp (2001). The unique characteristics of this subject's LP maps will be described, specifically highlighting increased $2f_1$-$f_2$ and $2f_2$-$f_1$ DPOAE levels. These findings exemplify that DPOAE changes are complex and more research is needed before DPOAE measurements can be simply implemented into hearing loss prevention programs. Additionally, these data suggest that DPOAE L/P mapping may prove useful for expanding our diagnostic and monitoring abilities, as well as providing a better understanding of the mechanisms of cochlear damage from noise. Work supported by ONR Grant N00014-09-1-0859.

## INTRODUCTION

Otoacoustic emissions (OAEs) are low-level sounds produced by the cochlea's active amplifier in outer hair cells (OHCs) and reverse transmitted through the middle ear into the external auditory canal, where they can be detected by a sensitive microphone (Kemp 1978). These sounds occur spontaneously in the majority of normal ears, and they can be deliberately evoked by presenting an acoustic stimulus to the ear. OAEs are diminished, and can disappear entirely, in instances of sensory hearing loss (Harris 1990; Gorga et al. 1999).

One particular type of evoked OAE is called the distortion-product otoacoustic emission (DPOAE). This class of evoked emission is elicited by the simultaneous presentation of two pure-tone stimuli. DPOAEs are particularly appealing as a clinical measure because the two tones, termed $f_1$ (lower frequency) and $f_2$ (higher frequency), can be swept in frequency and amplitude to form a DP-gram, in a manner very similar to procedures routinely used to obtain a clinical hearing test (audiogram). The DP-grams can then be related to the subjective hearing capability of the same individual (Gorga et al. 1999).

Due to the non-linear amplification mechanism of the cochlea, the presentation of two pure-tones to the ear actually results in a family of distortion-product emissions of which the $2f_1$-$f_2$ and the $2f_2$-$f_1$ DPOAEs (Figure 1) are the most prominent members (Brown & Kemp 1985; Lonsbury-Martin et al. 1987). In humans, the $2f_1$-$f_2$ emission has the highest absolute magnitude and the $2f_2$-$f_1$ the next highest. Both of these

DPOAEs are available from the signal-amplitude spectrum of the measured ear-canal sound. In current clinical practice, the $2f_1$-$f_2$ is used as a diagnostic indicator for impaired cochlear function. Varying the stimulus frequencies ($f_1$ and $f_2$) provides an assessment of the functional integrity along the length of the basilar membrane. The optimal stimulus ratio ($f_2/f_1$) is 1.22 for clinical DP-Grams when measured with stimulus levels of $L_1$ = 65 dB SPL and $L_2$ = 55 dB SPL (Gaskill & Brown 1990; Harris et al. 1989). For the $2f_2$-$f_1$ DPOAE, the optimal $f_2/f_1$ ratio is 1.12 (Erminy et al. 1998). To distinguish normal-hearing ears from hearing-impaired ears, Gorga et al. (2000) found that DPOAE test performance improved by measuring and analyzing both the $2f_1$-$f_2$ and the $2f_2$-$f_1$ DPOAEs.

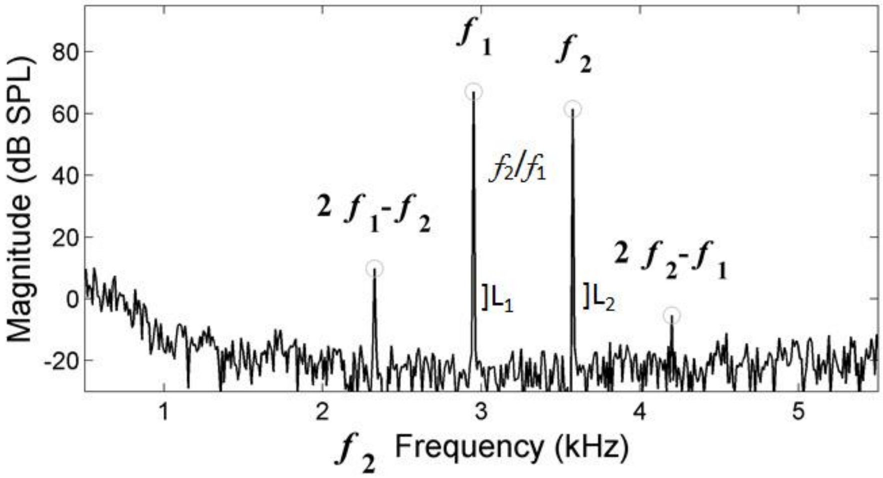


**Figure 1:** DPOAE acoustic stimuli and response recorded from the ear canal in a human

The cochlear generator sites for various DPOAEs are complex and appear to be different for the $2f_1$-$f_2$ emission as compared to the $2f_2$-$f_1$ DPOAE (Brown & Kemp 1985; Martin et al. 1998). Generally, the origins of these DPOAEs are presumed to be simultaneously generated at two places: at a characteristic place (CP) of $f_2$; and at the CP of each DP frequency. Ultimately, the DPOAE recorded in the ear canal contains a mixture of energy from more than one physical location on the basilar membrane. However, one of these sources typically dominates the DPOAE. The $2f_1$-$f_2$ DPOAE generator site is theorized to primarily arise from a place that is apical, at the geometric-mean frequency of the primary tones. In contrast to the $2f_1$-$f_2$ DPOAE, the $2f_2$-$f_1$ DPOAE appears to originate from a source more basal to the primary-tone place on the basilar membrane (Martin et al. 1998).

Knight & Kemp (2001) used a fixed-ratio level and phase mapping technique to demonstrate the source differences between the $2f_1$-$f_2$ and the $2f_2$-$f_1$ DPOAEs. In their approach, the dominance of one source over the other appears to be a function of primary-tone $f_2/f_1$ ratio and is evident in phase pattern differences. For the $2f_1$-$f_2$ DPOAE, a dominant $f_2$ related generator (wave-fixed phase pattern) is evident for $f_2/f_1$ ratios greater than 1.1-1.15. For frequency ratios of less than 1.1-1.15, a DP frequency (place-fixed phase pattern) generator source is dominant. Both source mechanisms are equally present at ratios between 1.1and 1.5. In contrast, the DP frequency (place-fixed) component dominates at all $f_2/f_1$ ratios for the $2f_2$-$f_1$ DPOAE.

Hazardous noise or sound levels are known to cause both temporary and/or permanent inner ear damage, especially to outer hair cells (Hamernik et al. 1989, 1996).

Therefore, changes in outer hair cell electromotility have been explored with OAEs. It is possible that OAEs may be more sensitive to early signs of noise-induced hearing loss (NIHL) and may be useful in determining susceptibility to NIHL (Lapsley Miller & Marshall 2007). Similar to pure-tone testing, DPOAEs can be used to detect a temporary vs. a permanent change (shift) in cochlear status as a consequence of hazardous noise exposure. Both a temporary emission shift (TES) and a permanent emissions shift (PES) can be measured relative to a baseline measurement when the individual serves as their own control and when DPOAEs are measured before and after noise exposure (Attias & Bresloff 1996). In a laboratory environment, the TES time-course for recovery qualitatively resembles the temporary threshold shift (TTS) recovery functions (Rossi et al. 1991; Sutton et al. 1994).

A reduction in measured DPOAE levels is commonly associated with cochlear damage from hazardous noise; however, some researchers have reported sporadic instances of increased DPOAE levels in noise exposed subjects (Lonsbury-Martin & Martin 1990; Avan et al. 1996). Martin et al. (2005) performed DPOAE LP mapping on rabbits and noted that noise-damaged rabbit ears show more vertical phase banding at narrow ratios when compared to the non-exposed control ear. More recently, we have studied one such normal hearing individual before and after exposure to hazardous occupational noise (400 % noise dose) using a series of DPOAE level/phase (LP) maps.

## OBJECTIVE

This single case study was collected as part of a larger study to determine the effects of hazardous noise exposure on various distortion-product measures of cochlear function. Specifically, we are measuring DPOAE LP maps in three experimental groups: normal-hearing ears without noise exposure; normal-hearing ears with a positive history of noise exposure; and high-frequency hearing-impaired ears using both a cross-sectional and longitudinal study design. This case study subject comes from the normal-hearing, noise-exposed experimental group.

## METHODS

Pure-tone hearing tests were obtained using a GSI 16 audiometer calibrated to American National Standards Institute (ANSI) S3.6 – 2004 and conducted in a single-walled Interacoustics sound booth meeting ANSI S3.1-1999 (R2008; 2003) permissible ambient noise level requirements. Tympanometry screening at 226 Hz was conducted with an EROScan (Etymotic Research) system. Both audiometry and tympanometry screenings were conducted prior to DPOAE mapping.

DPOAE LP maps were obtained with the prototype Creare Hearing Assessment system (Creare, Inc., Hanover, NH). The system includes an Etymotic 10B+ probe with ER-2 speakers (Elk Grove, IL), a USB data acquisition card (Data Translation, DT9841E), and custom software to execute the DPOAE tests via a laptop PC. The probe's microphone amplifier was set to provide a sensitivity of 0.5 V/Pa. For DPOAE measurements, the USB data acquisition card drives the speakers and synchronizes recording with the microphone signal at 44.1 kHz with 24-bit resolution. Data from the tests were stored in a Microsoft Access database and additional post-processing analysis was performed in MatLab.

DPOAEs were measured in DPOAE frequency steps of approximately 44 Hz (0.5-6.0 kHz) in response to primary-tone sweeps at two levels; 65,55- and 75,75 dB SPL using constant f2/f1 ratios. To construct the DPOAE LP maps, each frequency sweep was repeated at ratios incremented in 0.025 steps (1.025-1.5). DPOAE levels were directly plotted in dB SPL and color-coded to facilitate visualization in a DPOAE level map. DPOAE phase maps were generated by plotting the unwrapped phase of the DPOAE relative to the phases of the two primaries. For the $2f_1$-$f_2$ DP, the phase is computed at $p_{dp}$-(2 $p_1$-$p_2$), where $p_{dp}$ is the phase of the DP, $p_1$ is the phase of the primary $f_1$ and $p_2$ is the phase of the primary $f_2$. For the $2f_2$-$f_1$ DP, the phase is computed as $p_{dp}$-(2 $p_2$-$p_1$). DPOAE phase was plotted in degrees and color-coded on a scale of 0 to 360°. A repeated LP maps was measured.

The test-retest repeatability is defined as the expected variation in DPOAE levels between repeated measurements when no change in hearing is expected; it is computed as the average absolute level difference between a repeated level map and the baseline map for all points that meet a 3 dB Signal-to-Noise-Ratio (SNR) criterion above the noise floor. The test-retest repeatability was experimentally determined by taking repeated DPOAE maps for a normal-hearing subject under controlled conditions on the same day, next day and over the course of several months, using the same measurement setup and the same test administrator. Probe position was measured acoustically during the initial test session and subsequent probe placements were matched acoustically to the baseline position reference. The resulting computed test-retest repeatability was 2.5 dB.

Noise exposure was measured during one single work shift using the ER200 personal noise dosimeter (Etymotic Research). The noise dosimeter was pre-programmed to calculate noise dose using the following parameter set: A-weighting, slow response; threshold level of 75 dBA; 3-dB exchange rate; criterion level of 85 dBA; and criterion time of 8 hours. Noise doses above 100 % exceed the National Institute for Occupational Health and Safety (NIOSH) recommended noise exposure guideline for risk of NIHL if exposed over extended periods of time.

## RESULTS

The case study subject is a 26 year-old male employed in the construction industry. The left ear was tested. Hearing thresholds were ≤15 dB HL for 250-8,000 Hz at both mapping sessions and tympanometric peak middle ear pressures were between 0 and -100 mm$H_2O$.

The initial baseline DPOAE level maps were obtained after 14 hours away from loud workplace or recreational or music noise exposure (Figs. 2A and 2C). The subject was enrolled in a separate longitudinal study and returned in 4 months for the routine second mapping session after work a full shift at a construction site. The retest map was obtained on the same day as the noise dosimetry study which revealed a noise dose of 400 % (Figs. 2B and 2D). The subject does not routinely wear hearing protection due to the intermittent nature of the occupational noise sources, although he has been advised to do so. DPOAE responses were 4.2 dB higher on average after noise exposure. In addition, there were more detectable DPOAE responses for the $2f_2$-$f_1$ DP over a broader range of ratios, especially in the 3- to 6 kHz $f_2$ frequency range; these appeared to be consistent with “place-fixed” phase patterns.

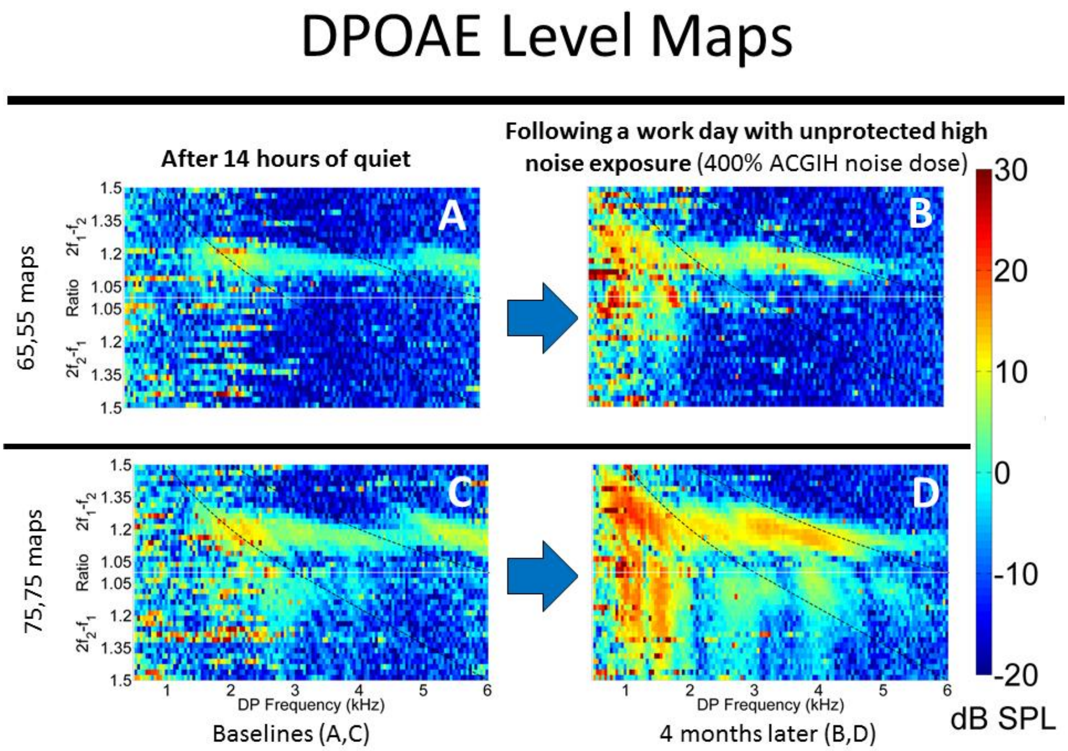


**Figure 2:** DPOAE level maps obtained 4 months apart in one male subject. Baseline (A,C) and re-test after noise exposure (B,D) obtained at two stimulus levels 65,55 dB SPL (A,B) and 75,75 (C,D). Dotted lines represent $f_2$ at 3 kHz and 6 kHz

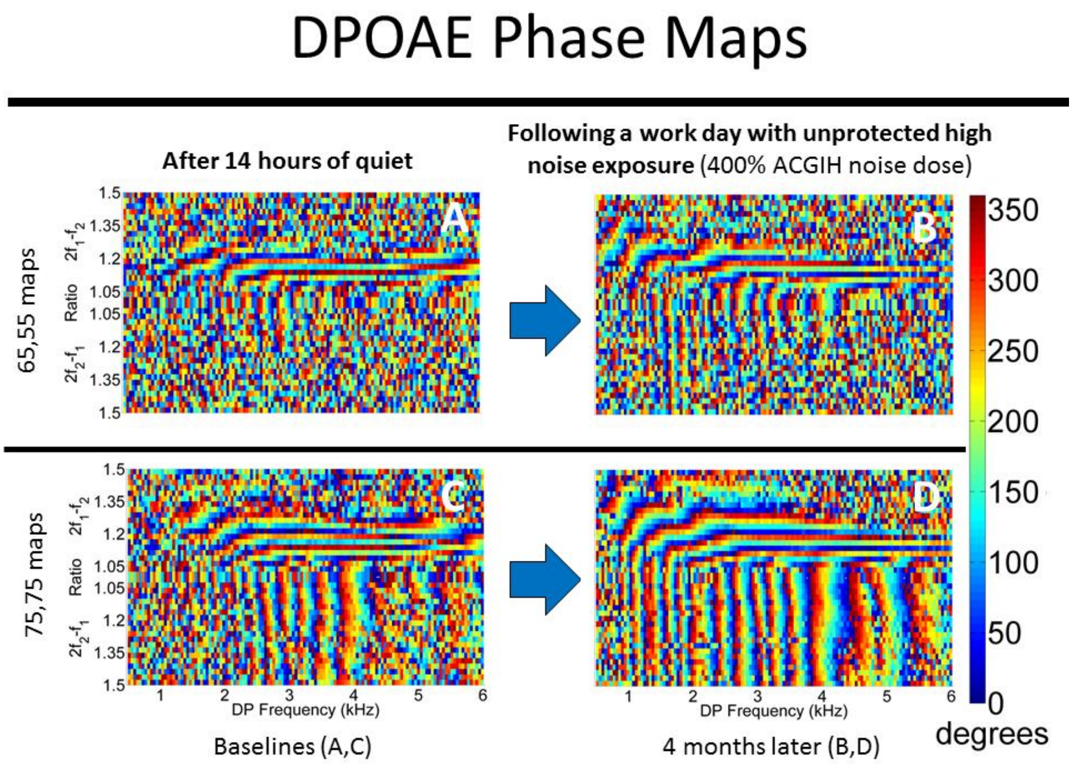


**Figure 2:** DPOAE phase maps obtained 4 months apart in one male subject. Baseline (A,C) and re-test after noise exposure (B,D) obtained at two stimulus levels 65,55 dB SPL (A,B) and 75,75 (C,D)

## DISCUSSION

The increase in DPOAE responses after noise exposure may be attributed to a change in the relative contributions of the “place-fixed” and “wave-fixed” components in subjects with NIHL due to an expected change in the localized random changes in stereocilia or outer hair cells as a result of the hazardous sound levels. This appears to be supported in the changes evident for our human subject in the $2f_2$-$f_1$ map area; as explained earlier; the $2f_2$-$f_1$ emission is dominated by “place-fixed” sources. In addition, the results for this human subject are consistent with changes in a DPOAE level/phase LP map obtained on rabbit ears with and without noise exposure (Martin et al. 2005). Martin et al, noted that it is not clear whether these emissions were “created” as a consequence of the noise exposure or if they may have been present previously but “unmasked” due to a change in the relative contributions of two DPOAE sources that may have interfered with each other.

This single case study has some limitations. Other factors aside from noise could have affected this individual’s DPOAEs in the time between the baseline and post noise-exposure measurements. In addition, subtle middle ear differences that influence the reverse transfer function of the DPOAEs may exist at the time of DPOAE LP mapping session(s) and these subtleties may not be detectable with the traditional immittance techniques used in this study. Nevertheless, researchers investigating DPOAE changes relative to noise exposure should consider the potential for bi-directional changes in DPOAE magnitude over time. This subject will continue to be monitored longitudinally and phase maps further analyzed for elucidation of relative source contributions.

## SUMMARY

DPOAE LP mapping has the potential to identify widespread changes in the DPOAE responses before and after noise exposure and to provide a much more comprehensive assessment of cochlear function than is possible with traditional limited frequency DP-Grams. DPOAE level changes may be more complex than originally reported and further investigation using longitudinal studies is warranted.

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# Usage of personal music player among teenagers and young adults in Malaysia

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## BACKGROUND

In recent years, the usage of personal music player (PMP) as a music listening tool has been on the rise. PMP is a device that has the function of storing, organizing and playing audio files in digital format (eg: MP3 players, mobile phones and laptops). MP3 players are the most widely chosen listening device due to its small size, affordable price, big storage of songs and longer battery life. In the US, it is reported that 14.5 million units of MP3 players were sold in 2008 (News 27 November 2008). The trend of using one of these gadgets has also spread to Malaysia. It is reported that more than 7.5 million mobile phones valued at over 4.5 billion ringgit was sold in Malaysia in 2010 (Knowledge 2011). Its usage has been increasingly popular, especially among adolescents and young adults. Concerns have been raised regarding its effect on hearing. Especially since the usage of PMP does not come with any guidelines of safe listening habits. Most young users are less concerned regarding the risk of hearing impairment from exposure to loud music via PMP or other sources (Chung et al. 2005; Rawool & Colligon-Wayne 2008; Vogel et al. 2008). Furthermore, adolescents are known to have risky behavior and self-exposure to noise (Bohlin & Erlandsson 2007).

To date, there is no universal safety standard for listening to music. The safety guidelines outlined by the National Institute for Occupational Safety and Health (NIOSH) and Occupational Safety and Health Administration (OSHA) on noise exposure is based on industrial noise(OSHA 1983; NIOSH 1998). Noise is continuous with relatively unchanging temporal and spectral content as opposed to music that have more variation. It is the variation in the music that makes it difficult to set a safety guideline for listening to it. Fligor & Cox (2004) tested 10 different types of CD and MP3 players. Their results show that the output levels are between 70-115 dBA for volume gain setting of 5-10 (Fligor & Cox 2004; Portnuff & Fligor 2006). This volume output is then compared to the permissible noise exposure stated by NIOSH and OSHA. Based on this comparison, Fligor & Cox (2004) recommended that the safe limit to use PMP is at 60 % of the maximum volume for 60 minutes (CD player) and 80 % of maximum volume for 90 minutes (MP3 player) in any 24-hour period.

The prevalence of sound exposure and the resultant effect on hearing threshold is still a subject for a debate. Results from previous studies are equivocal. Table 1 summarizes the reports which supported that PMP could cause hearing impairment. There are researches that studied the listening habit of users with the output level from the device used. Data from these studies agrees that prolong usage of PMP at a loud volume could lead to noise-induced hearing loss (NIHL) (Catalano & Levin 1985; Rice et al. 1987a, b; Trask et al. 2006; Vogel et al. 2010). Other studies supported their findings with evidence from pure-tone audiometer (PTA) test. It shows that there is an increase in hearing threshold shifts among PMP users (Peng et al. 2007; Kim et al. 2009; Keppler et al. 2010). In studies that cover the effects of recreational noise exposure (including PMP usage), they found the evidence of hearing loss in both conventional and high frequency audiometer (Axelsson et al. 1981; Meyer-Bisch 1996; Biassoni al. 2005; Serra et al. 2005). The research done by Serra et al. (2005) and Biassoni et al. (2005) followed up on the subjects for four years, and it shows evidence of hearing threshold shifts from recreational noise exposure.

**Table 1:** Summary of studies that supported the usage of PMP could cause hearing impairment

| Author/Year | Subjects | Sample Population | Method | Result/Conclusion |
|---|---|---|---|---|
| Axelsson et al. (1981) | 538 | -Age 17-20<br>-Subjects have exposure to noisy leisure activities (incl personal cassette player). | -Questionnaire<br>-Audiometry test (0.25-8 kHz) | -15 % incidence of hearing loss.<br>-6 kHz most affected, suggesting noise etiology |
| Catalano & Levin (1985) | 154 | -College students<br>-Age 18-21 | -Questionnaire<br>-Measure sound output from stereo-cassette player | 31.4 % equaled or exceeded maximum allowable noise dose |
| Rice et al. (1987a) | 61 | -Regular personal-cassette player (PCP) users<br>-Random PCP users in the street | -Questionnaire<br>-Measure output from PCP | -25 % exposed to loudness of 90 dBA.<br>-5 % exposed to loudness >100 dBA |
| Meyer-Bisch (1996) | 1722 | -Age 14-40<br>-PCP users; night club, rock concert attendees and staff; musicians; music teachers | -Questionnaire<br>-Audiometry test (0.125-16 kHz) | -PCP user of >7 hour/week have higher threshold than control at 2-16 kHz. |
| Serra et al. (2005)<br>Biassoni et al. (2005) | -173; longitudinal study.<br>-after 4 years only 106 subjects | -Age; start at 14 until 17.<br>-subjects involved in noisy recreational activities (incl. PMP use) | -Questionnaire<br>-Audiometry test (0.25-16 kHz) | -Increased in hearing threshold after 4 years.<br>-Boys higher threshold than girls. |
| Trask et al. (2006) | 95 | -university students | -Questionnaire<br>-Measure output from personal audio device (digital) | -16 % exposed to loudness >100 dB.<br>-43 % at risk for hearing loss (based on NIOSH criteria).<br>-17 % at risk of hearing loss (based on OSHA criteria). |
| Peng et al. (2007) | 150 | -Age 19-23 y.o.<br>-Students at Wuhan University | -Questionnaire<br>-Audiometry test (0.5-20 kHz) | -Impaired hearing in 14.1 % (34 of 240 ears) of ears among personal listening device users. |
| Kim et al. (2009) | 490 | -Age 13-18<br>-Middle and high school students | -Questionnaire<br>-Audiometry test (0.5-4 kHz) | -Significant threshold increase in PMP user of >5 years, used >15 years cumulative period and who used earphones. |
| Vogel et al. (2010) | 1,512 | -Age 12-19<br>-Dutch schools | -Questionnaire<br>-Estimates sound output from other study | -32.2 % MP3 player users exceed threshold of music exposure. |
| Keppler et al. (2010) | 49 | -Age 19-28 | -Subjects exposed to 1 hour of pop rock music.<br>-Pre and post-exposure audiometer (0.25-8 kHz) and otoacoustic emission. | -Significant changes in hearing threshold of noise exposure group between pre and post-exposure measurements. |

However, not all previous studies are in agreement with the research data mentioned in Table 1. Table 2 summarizes previous studies that concluded there is no relationship between PMP usage and NIHL. There are studies that looked at the output level from PMP and comparing it to the safety noise exposure available in their country. They reported that the volume setting used by listeners is not hazardous to hearing (Turunen-Rise et al. 1991; Williams 2005; Torre 2008; McNeill et al. 2010; Kahari et al. 2011). Other authors did not find statistically significant relationship between the usage of PMP and hearing loss (Carter et al. 1982; Wong et al. 1990; Mostafapour et al. 1998; Tambs et al. 2003; Shah et al. 2009). Nevertheless, they all agreed that individuals listening to PMP are at a very low but not zero risk of NIHL. They concluded that the majority of listeners are able to self-regulate their listening habits by listening at a low volume. This allows them to listen to the PMP longer without reaching the maximum exposure level that would cause NIHL.

**Table 2:** Summary of studies that concluded there is no relationship between PMP and hearing impairment

| Author/Year | Subjects | Sample Population | Method | Result/Conclusion |
|---|---|---|---|---|
| Carter et al. (1982) | 944 | -University students age <21. | -Questionnaire<br>-Audiometry test | -No wide-spread hearing loss caused by amplified music. |
| Wong et al. (1990) | 487 | -Age 15-24 | -Questionnaire<br>-Audiometry test (0.25-8 kHz) | -Most youths used PCP safely with low risk of hearing loss. |
| Turunen-Rise et al. (1991) | 6 | -Age 23-40<br>-Normal hearing subjects, exposed to 1 hour of music. | -Measure output of PCP.<br>-Audiometry test pre and post exposure (1-8 kHz) | - Exposure level to PCP users are lower than those implying risk of hearing loss. |
| Mostafapour et al. (1998) | 50 | -Age 18-30<br>-College students exposed to amplified music (incl. personal listening devices) | -Questionnaire<br>-Audiometry test (0.25-8 kHz) | -No evidence of hearing loss from personal listening device use or other recreational noise. |
| Tambs et al. (2003) | 5,1975 (national study in Norway) | -Age 20-101<br>-Exposed to impulse noise, personal stereo players, disco and concerts. | -Questionnaire<br>-Audiometry test (0.25-8kHz) | -No significant effect from frequent use of personal stereo player, exposure to disco or concerts. |
| Williams (2005) | 55 | -Individuals passing by in the streets using personal stereo players (PSP) | -Questionnaire<br>-Measure PSP output. | -In majority of users, no significant increase of hearing loss from PSP alone. |
| Torre (2008) | 1048 | -University Students<br>-1016 complete questionnaire<br>-32 test for loudness of PMP | -Questionnaire<br>-Measure PMP output | -Volume setting that they listened to is not hazardous to hearing. |
| Shah et al. (2009) | 94 | -Age 18-65<br>-Campus recreation facility | -Questionnaire<br>-Audiometry test (0.5-4 kHz) | -No significant relationship between PMP use and hearing loss. |
| Kumar et al. (2009) | 100 | -Age 17-24<br>-PMP user and control | -Questionnaire<br>-Measure output of PMP<br>-Audiometry test (2-12 kHz)<br>-DPOAE | -30 % listened to music above safety limit.<br>-No significant difference of mean hearing threshold between user and control groups. |
| McNeill et al (2010) | 28 | -University students<br>-Age 17-23 | -Questionnaire<br>-Measure MP3 players output | -Majority subjects used MP3 players in a way that would not increase their risk of hearing loss. |
| Kahari et al. (2011) | 60 | -Average age 33 years<br>-Passer-by at Stockholm Central Station using PMP | -Questionnaire<br>-Measure output of PMP | -Could not establish correlation between volume level and hearing loss |

Presently there is no data on the usage of PMP among teenagers and young adults in Malaysia. We conducted a preliminary study to determine their listening habits, PMP of choice, hearing-related symptoms and prevalence of hearing loss among teenagers and young adults in selected areas in Kuala Lumpur.

## METHOD

A study was conducted on 230 University of Malaya students (18-30 years) and 244 students (13, 14 and 16 years) from 3 high schools within the Klang Valley area. All subjects were screened using otoscope to rule out any impacted cerumen or ear canal abnormality. Any middle ear function abnormality was ruled out using air-bone conduction gap in the university students group and tympanometry for the high school students group.

A face-to-face interview was conducted to elicit information on age, gender, the duration of usage, types of PMP used and any hearing-related symptoms. Their ideal listening volume was determined by doing an iPod volume test. Subjects were given an Apple iPod Nano ($4^{th}$ generation), coupled with an insert earphone (Sony MDR-EX51LP). They were asked to listen to a standard song (Just Like Heaven.mp3 by artist The Cure) from the iPod. Subjects, who were blinded to the volume scale, were instructed to increase the volume to the loudness that they preferred. The volume scale length was between 0-2.2 cm which represents 0-100 % from maximum volume. The volume was then measured and converted to percent. This reading was later converted to loudness in dBA using a G.R.A.S. artificial right ear and cheek simulator (type 43AG) and type 1 sound level meter (Norsonic nor140).

A diagnostic audiometer (Siemens SD28) with audiometric test booth (ATS 200) was used for the hearing test. The audiometer has frequency range from 0.25–16kHz with the smallest intensity increment or decrement of 1 dB. A supra-aural headphone (Sennheiser HD 200) was used for air-conduction test in all frequency range. Threshold finding was performed using the modified Hughson-Westlake up-down procedure (Katz et al. 2009). Hearing threshold was established at each frequency.

## RESULT

Our initial finding shows 80 % of the 474 subjects (134 males, 246 females) were PMP users. Majority of subjects in both groups preferred the use of mobile phones as music listening tool compared to other types of PMP (laptop, mp3 player and CD player). Fifty-nine percent of all users experienced at least one of the following symptoms (tinnitus, headache, neck stiffness, ear pain and difficulty hearing others). Age and gender appeared to influence listening pattern. Female university students listened for a significantly longer duration (17.2±18.2 hrs/wk) than male university students (12.5±11.7 hrs/wk). On the other hand, male high school students listened at significantly higher volume (78.4±10.2 dBA) than female high school students (73.3±10.7 dBA). PTA revealed increased hearing threshold in 27 university students and 24 high school students. However, no significant correlation was found between listening behavior and incidence of hearing impairment.

## CONCLUSION

Our preliminary study investigates the usage of PMP and hearing loss in the studied population. More data is needed to establish the relationship between PMP usage and its impact on hearing.

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# Advanced hearing protection and communication: progress and challenges

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## INTRODUCTION

Noise remains a major problem in many industrial and military work environments. In addition to increasing the risk of permanent hearing loss, high noise levels can cause temporary hearing loss, and compromise speech communication and the perception of important signals from the environment. While the preferred method to mitigate the effects of noise is through engineering control measures at the source, this is not always technically possible or practical, and hearing protectors remain a mainstay of hearing loss prevention programs (Gerges & Casali 2007; Canetto 2009). Broadly speaking, hearing protectors can be classified as active or passive devices, whether or not powered electronic circuitry is incorporated into the design. Conventional protectors are of the passive type and are still the most commonly used. They provide a fixed attenuation irrespective of the noise level in all but the most extreme noise situations. Unfortunately, they also reduce speech and other important sounds from the environment, and a compromise in the amount of attenuation provided must be established for optimal protection, safety and work efficiency.

Some standards (CAN/CSA Z94.2-02 R2007; EN 458:2004) recommend selecting hearing protectors so that the protected level falls 5-10 dB below the occupational limit (typically 85 dBA), but this goal is difficult to achieve in practice. Firstly, the attenuation provided by hearing protectors varies widely across individuals depending on the ear geometry, fitting proficiency and motivation, among other factors, and the real-world attenuation is often far short and poorly related to current performance ratings and labelling of hearing protectors (Williams 2009). Secondly, even if the effective attenuation can be ascertained, workplace noise is rarely constant over time or uniform spatially. Thus, the protected level will vary in a given day with periods of overprotection and periods of insufficient protection. Workers generally view hearing protectors as an inconvenience and often perceive them as an impediment to information exchange and work performance, especially in the presence of a pre-existing condition of hearing loss (Abel 2008; Canetto 2009; Casali 2010).

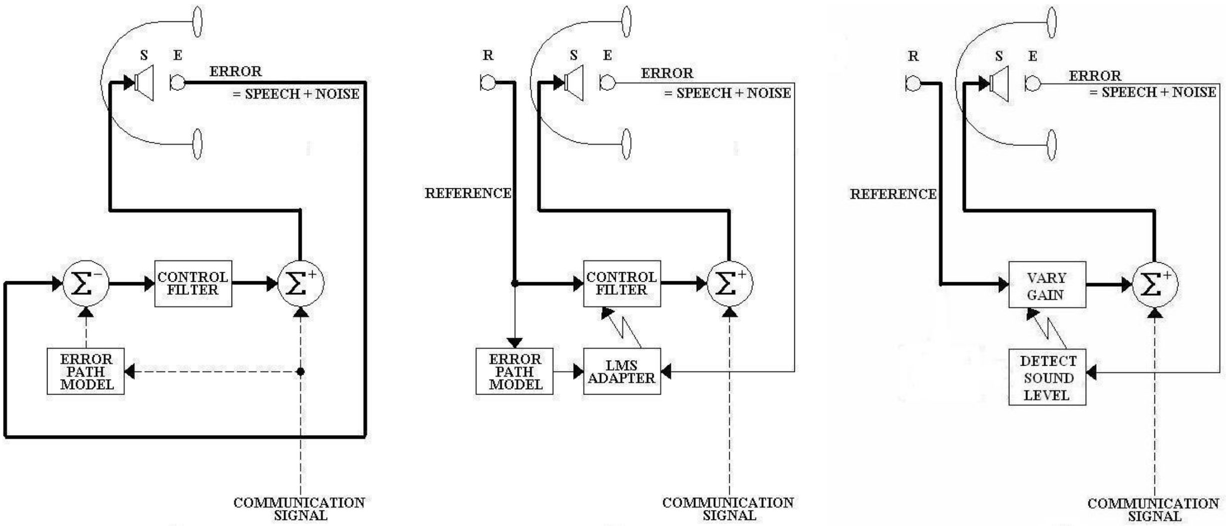
Advanced active hearing protection devices are rapidly being introduced into the marketplace with the dual purpose of providing effective protection against noise and enhancing communications. In some of the most challenging environments and work situations, the devices must protect hearing against hazardous continuous and impulse noise while maintaining good situational awareness (e.g. warning signal perception, sound localization, speech communication, detection of distant events) within the immediate surroundings and over radio communications. This paper provides an overview of recent developments, current approaches and issues in advanced active hearing protection and communication devices, and builds on the recent reviews by Brammer et al. (2008) and Casali (2010).

## DESIGN CONSIDERATIONS

Rapid advances in electronics and dedicated digital signal processors in the past few years have led to a resurgence of interest in hearing protectors containing microphones, earphones and other electronic components. Typically, these devices aim to achieve one or more of the following objectives: increase the protection afforded over the passive attenuation of the device by means of active noise reduction (ANR) or phase-cancellation technology, enhance awareness of sounds in the surrounding environment through level-dependent attenuation, and incorporate radio channel capabilities for remote communications.

### Active noise reduction

Figures 1a and 1b contrast the control structure of the traditional analog feedback ANR to that of the feedforward approach more commonly found in digital devices. The ear cup and cushion are shown in cross sectional view. The ear cup contains a miniature earphone (S) and one or more microphones (E and R). The thick lines show the path taken by the environmental noise.




a b c

**Figure 1:** Three basic schemes found in advanced hearing protectors as applied to an earmuff design: (a) feedback ANR, (b) feedforward ANR, and (c) level-dependent circuitry

In the feedback configuration (Figure 1a), a control filter acts to cancel the sound pressure at E. The main elements of this process are the transformation of the electrical signal to sound by the earphone S, the propagation of sound from S to E and the transformation of sound into an electrical signal by the microphone E. These transformations define the transfer function from S to E, which is termed the error path. In essence, microphone E detects the "error" in the cancellation of the environmental noise. Feeding back the output of the error microphone to the input of the control filter ensures that there is a continually updated correction to the performance of the control system. Owing to the delay for sound to propagate from S to E and the requirement to maintain stability, the maximum frequency for which active reduction can be achieved is typically limited to about 1,000 Hz for earmuffs and 2,000 Hz for earplugs (Brammer et al. 2008).

In the feedforward configuration (Figure 1b), a reference microphone R is used to sense the noise just outside the ear cup. An adjustable filter controls the intensity of the reference signal R. The control system accounts for the transmission of sound through the device, by using microphone E to sense the residual noise within the ear cup. In practical applications, sound cancellation is implemented digitally by an adaptive filter, the coefficients of which are commonly derived through a Least Mean Square (LMS) algorithm or its variants. Such an algorithm is most effective when it includes a model to represent the transmission of sound from S to E, which is termed the error path model. The time available for processing the reference noise signal cannot exceed the time taken for sound to propagate from R to S, typically about 150 µs. This constraint ultimately limits the complexity of algorithms that may be employed. Within this limitation, environmental noise may be reduced at frequencies typically below about 800 Hz, for earmuffs. The addition of a high-frequency active noise control system, operating in the range from about 800 to 1,600 Hz, is also possible to broaden the effective ANR bandwidth. Feedforward systems can also be effective to reduce tonal components and band-limited environmental noise in the range as high as 2,000-3,000 Hz (Casali 2010).

**Level-dependent attenuation**

In contrast to the ANR schemes, the pass-through structure is designed to amplify sounds reaching the ear by an amount varying according to the surrounding sound level. Devices employing such structure are often termed level-dependent hearing protectors. Figure 1c illustrates the similarities and differences with the feedforward concept (Figure 1b). A level-dependent hearing protector employs the same electro-acoustic components (microphones E and R, earphone S) as a feedforward device. However, the processing blocks have different functions. Provided that the sound level at E is below a maximum based on established limits for occupational noise exposure, the environmental sounds sensed by microphone R are amplified, and then fed to the earphone S to improve their audibility. This processing may involve analog or digital electronics. In simple designs, both speech and environmental noise are amplified usually with a preference for frequencies in which speech sounds are to be expected (e.g. frequencies > 125 Hz). This processing can improve audibility for environmental sounds that decrease in intensity with increasing frequency.

In Figure 1c, a detector continuously monitors the sound level under the ear cup at E. When the sound level exceeds a predetermined value, the gain from S to E is immediately reduced. In simple designs, the gain is kept constant, and the device behaves as a linear amplifier, when the sound level under the ear cup is below the upper limit. Other systems incorporate automatic gain control (AGC) to achieve a more gradual gain reduction over the range of external sound levels. Even more advanced designs employ complex algorithms that attempt to preferentially amplify the speech of a talker in front of the user. It is important to note that the gain block in Figure 1c is not only under direct control of the detector, but the user may manually vary the base gain through a volume control, typically over a range of 12-18 dB but sometimes more, or turn the amplifier off to achieve passive-only protection. Depending on the location of the volume control within the AGC circuitry, input- or output-sensitive compression functions akin to hearing aids can be realized.

Figure 2 shows the at-ear sound levels produced by an active level-dependent earplug on an acoustic manikin as a function of the incident free field sound level for a frontal speech-spectrum noise stimulus. Each curve represents a different talk-through gain setting, except for the curve with open diamonds which represents the open-ear function (no device fitted). Data points above (or below) the open-ear curve indicate that the device amplifies (or reduces) external sounds. In Figure 2, manikin levels increase with stimulus levels for all gain settings up to an upper limit. As expected, at-ear levels are higher with increasing gain settings at low-to-moderate stimulus levels (< 70 dBA). The shape of the curves for gain settings 6 and above shows that the device incorporates output-sensitive gain control set to a maximum at-ear level of around 92 dBA [Note that difference between open-ear and free-field levels is 8 dB, so that this upper limit corresponds to an equivalent free-field level of about 84 dBA]. Other features include input-sensitive compression characteristics at a free-field threshold of 80 dBA with a compression ratio of about 4:1.

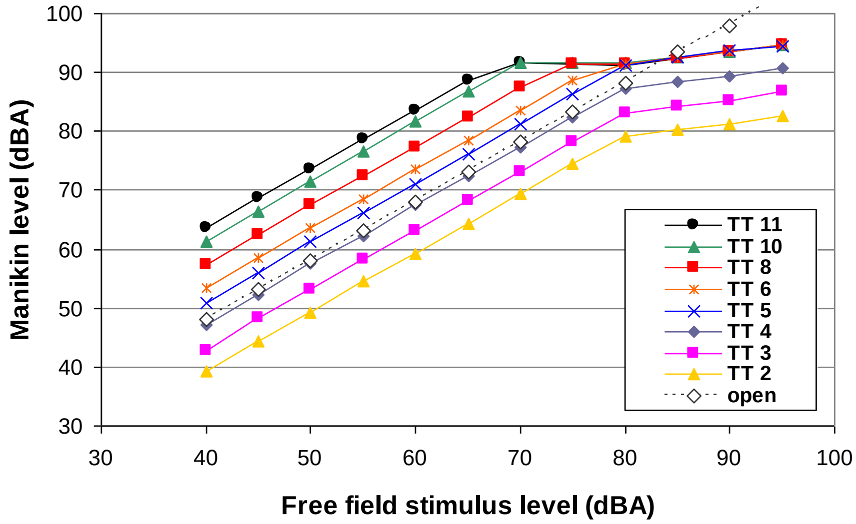



**Figure 2:** Level functions for a level-dependent communication earplug for different talk-through (TT) settings. Open diamonds represent the open-ear function. Frontal speech-spectrum noise stimulus

Finally, combination of the basic schemes in Figure 1 is possible, e.g. feedback ANR with level-dependent attenuation. Many ANR and level-dependent devices are also equipped with a communication channel (shown by dashed lines in Figure 1). This signal is fed to the same earphone through a summation unit ($\Sigma^+$).

## FACTORS AFFECTING AUDITORY PERCEPTION

Table 1 lists some of the factors involved in the performance of auditory tasks from the perspective of a listener wearing hearing protection equipment. Common auditory tasks include signal detection (e.g. warning sound, distant audible cue), discrimination (e.g. machinery defect, different talkers) and recognition (e.g. speech understanding, source identification) as well as spatial localization of these sounds.

**Table 1:** Some factors involved in auditory perception and communication performance

| Tasks | Talker | Source factors | Environment | Listener |
|---|---|---|---|---|
| Detection | Gender | Power | Distance | Hearing protectors |
| Recognition | Vocal effort | Directivity | Reverberation | Binaural effects |
| Localization | Lombard effects | Spectrum | Noise field | Fluency |
| | Fluency/accent | Temporal char. | Competing sounds | Hearing status |
| | Orientation | | | Cognitive abilities |

Factors affecting speech production for a talker in the surrounding environment include gender and vocal effort (including the Lombard effect of naturally raising one's voice in noise), language fluency and accent, and the orientation of the talker with respect to the listener. Factors related to non-speech sources include the acoustic power and directivity of the sound radiated, and its spectral and temporal characteristics. The sound reaching the listener is modified by the transmission characteristics of the surrounding environment including distance, reverberation and other room acoustic effects, and may be degraded due to interfering noise sources or competing sounds. Factors affecting auditory perception include the use of hearing protectors and their performance characteristics, binaural effects related to the spatial distribution signal and noise, the signal-to noise ratio and the overall intensity, and the fluency, hearing status and cognitive abilities of the listener.

Communications carried over radio are affected by most of the factors above, but also include the characteristics and features of the pickup microphone at the talker's end, the quality of the radio transmission (especially distortions), and the acoustical characteristics of the communication signals presented to the listener in interaction with the environmental sounds passing through the passive or active hearing protection headset.

## REVIEW OF RECENT STUDIES

Most reports on advanced active hearing protectors have focussed on attenuation characteristics. Relatively few, independent, field and laboratory studies have been conducted to assess their benefits or drawbacks on auditory tasks and operational performance compared to conventional hearing protection or unprotected listening.

### Sound detection

Signal detection in quiet is generally superior with level-dependent hearing protectors than conventional hearing protectors, as expected due to their lower attenuation at low levels. When used at high amplification settings, they may even result in improved hearing thresholds compared to unprotected listening for hearing-impaired listeners, a benefit somewhat limited by the amount of audible masking hum from the device electronics for normal hearing listeners (Abel & Giguère 1997). Casali et al. (2009) showed that, in at least one active communication earplug with pass-through gain of 36 dB, the auditory detection distance improved by 80 % compared to unprotected listening, demonstrating the potential benefits in quiet of level-dependent hearing protection in tactical operations.

With regards to the detection of backup alarms in noise, data from Casali et al. (2004) indicate that hearing protectors with superior low-frequency attenuation, such as typically provided by ANR devices, may provide an advantage over conventional hearing protectors in some situations of intense low-frequency noise for normal hearing subjects. Such a benefit appears related to a reduction in the upward spread of masking into the signal frequency range (Casali et al. 2004; Brammer et al. 2008). Recent data collected in one of our laboratories (University of Connecticut) with a level-dependent earmuff indicate that the direction of the signal with respect to the user may be an issue for the detection of an alarm in noise. In some situations, near-perfect alarm detection can be achieved for frontal incidence while chance performance is obtained for signals from the back in the same diffuse noise field. This may be related to the directional characteristics or position of the external microphones on the ear cups.

### Sound localization

Differences were noted across studies concerning the benefits of advanced hearing protection devices for sound localization in quiet. Abel et al. (2007) found that two advanced communication systems (earplug and earmuff) were less detrimental than passive protectors in an 8-speaker identification task in the horizontal plane using broadband noise stimuli. The decrement in performance compared to unprotected listening were largely due to front-back reversal errors. In a follow-up study with the active earplug device in interaction with various military helmet configurations (Abel et al. 2009), the degradation in localization performance with respect to unprotected listening was relatively smaller, especially with helmet use, and related to fine front-back confusions between sources close to the interaural axis, which are less likely to impact on operational performance. However, in another study by Brungart et al. (2007), use of hearing protectors with level-dependent characteristics resulted in poorer localization performance than conventional hearing protectors for broadband noise stimuli, and even poorer performance compared to unprotected listening in a 3D sound localization task. However, the authors note that their results were much worse than those obtained for a different set of level-dependent hearing protectors in a previous study in their laboratory.

In a sound localization study carried out in traffic noise, Carmichel et al. (2007) evaluated three different active level-dependent earmuffs. Results indicated that the devices did not preserve localization abilities under most stimulus conditions, and reaction times were longer for familiar broadband stimuli with the active devices than unprotected listening. Alali & Casali (2011) investigated the sound localization of back-up alarms in pink noise for a range of seven active and passive earplugs and earmuffs. Overall, a dichotic level-dependent earmuff tested did not show an advantage for sound localization over a passive counterpart, and performed slightly worse than some passive earplugs in high noise levels. The difference was related to larger front-back errors.

### Speech recognition

Dolan and O'Loughin (2005) investigated the impact of one passive and three active level-dependent earmuffs on sentence recognition for listeners with sensorineural hearing loss. Speech recognition thresholds in 85 dBA industrial noise (speech and noise at frontal incidence) did not improve nor degrade by use of the passive device or the active devices set at the listener's preferred gain setting, despite greatly different gain characteristics across devices, compared to unprotected listening.

The impact of hearing protectors, active and passive, depend on the experimental conditions investigated. Recent data collected at the University of Ottawa is illustrative. Word recognition scores were obtained for frontal speech incidence in two military noises presented in a diffuse field at 80-95 dBA. The difference between protected scores with an active level-dependent earmuff under three different pass-through gain settings (off, low, high) and unprotected scores for four groups of subjects with different degrees of hearing loss is shown in Figure 3a. A positive difference indicates a benefit over unprotected listening. Normal-hearing subjects were unaffected by the device when used in the off position, which results in about 30 dB of passive attenuation, but subjects with hearing loss were negatively affected by an amount dependent on the degree of the loss, in agreement with previous studies on the impact of passive protection. In the low position, which provided about -4dB pass-through gain, a large benefit was obtained compared to the off position in the order of 25-60 % across subject groups. In the high position, which provided about +10 dB of pass-through gain, all subject groups showed an improvement of about 20-30 % with respect to unprotected listening, a very encouraging outcome.

Data collected at the University of Connecticut for normal hearing subjects in diffuse field low-pass pink noise show the effect of talker position for two active level-dependent earmuffs (Figure 3b). There is a 10-15 % word recognition benefit with respect to passive protection when the speech is frontally incident, but the converse occurs when speech is incident from the back. This again may be related to the directional characteristics or position of external microphones on the ear cups.

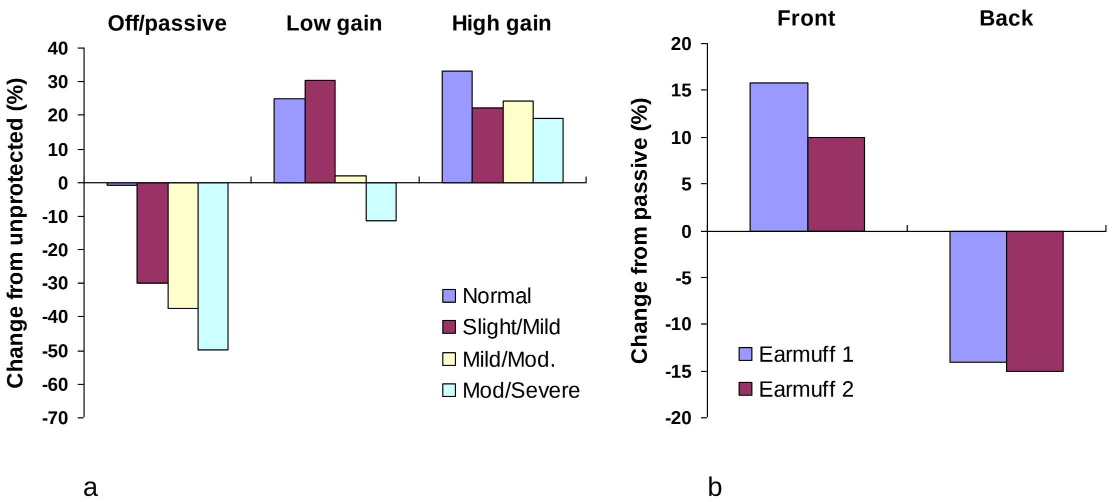



**Figure 3:** Speech recognition with two active earmuffs
(a) Data for Earmuff 1 for frontal speech as a function of pass-through gain and hearing loss
(b) Data for front and back incidence for both devices

Casali et al. (2007) investigated speech intelligibility and operational performance while using three ANR headsets and one passive device in a flight simulation experiment carried out over the communication channel. In adverse conditions, the three ANR devices led to less command repetitions than the passive headset and, in three of four measures of flight control, one ANR device led to better performance than the other devices. Also, subjects' ratings of workload was lower with the ANR headsets than the passive device. Further work is needed to uncover which specific design parameters of the headset are critical to flight performance.

## CONCLUSIONS

To our knowledge, as yet there is no device sufficiently engineered to restore reliably the situational awareness to that in the absence of a hearing protector in all situations but, as described above, progress is being made in a number of areas. Subjective impression by users is generally favorable to active level-dependent and ANR devices over passive protectors (Casali et al. 2007; Williams 2011; Tufts et al. 2011). However, only a limited subset of the factors listed in Table 1 has been investigated thus far, often for very specific listening situations or work occupations, and it has been difficult to generalize outcomes over different or even similar test conditions.

One impediment to future progress is the sparse and widely disparate disclosure of electro-acoustic technical data by manufacturers of advanced active hearing protectors, in sharp contrast to hearing aid manufacturers. Some progress is expected since the promulgation of standard ANSI/ASA S12.42 (2010); however, this new standard only focuses on the noise attenuation characteristics of the devices. Important parameters for situational awareness, such as the directional characteristics of microphones, compression parameters, internal noise, and harmonic distortion of pass-through and communication channels, are not addressed. Hence, it remains difficult to associate outcomes to specific technical parameters of the devices. This is needed to develop predictive models and tools to assist in the selection of the most appropriate device for specific situations as may be done, for example, for conventional hearing protectors (Giguère et al. 2010).

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# Update on fitness standards for hearing-critical jobs

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## INTRODUCTION

Since the last ICBEN meeting in 2008 only a few papers have been published on fitness standards for hearing-critical jobs, mainly in North America (Tufts et al. 2009; Vaillancourt et al. 2011; Corrections Standards Authority 2011). The last two publications report the efforts of two organizations in reviewing their hearing standards previously based solely on the audiogram, a measure of hearing sensitivity in quiet. It is now generally accepted that the audiogram is not sufficient in most cases for predicting auditory performance in workplaces where hearing-critical tasks must be performed efficiently to ensure worker and public safety. This is highlighted in a review by Tufts et al. (2009) on hearing standards for jobs where safety can be compromised (e.g. police officers, firefighters, correctional officers, coast guard officers, etc.).

Hearing standards are often dealt with from a purely medical standpoint, without taking into account workplace requirements. However, Auditory Fitness For Duty (AFFD) refers to the set of functional hearing abilities required for safe and effective job performance. For tasks (e.g. surveillance, rescue operations, piloting, military operations) in which the ability to respond to critical sounds or speech is paramount to successful operations and job safety, hearing loss can at times negatively impact performance to the point of being detrimental to worker and/or public safety. AFFD screening protocols should therefore provide valid assessments of functional hearing abilities that are free of discriminatory practices based solely on hearing loss (Tufts et al. 2009).

In the last few years, at least two organizations have demonstrated efforts in revising their hearing standards. The RCMP (Royal Canadian Mounted Police) has proposed functional criteria for officers wearing hearing aids on the job. As a growing number of officers were recommended the use of hearing aids since their hearing thresholds exceeded previously established audiometrically-based criteria and faced operational restrictions, timely implementation of these criteria was imperative, prior to work done to establish job-specific criteria. Over the last three years, over 80 officers were evaluated on measures of speech recognition in noise and sound localization to determine if they could be reintegrated into their job functions without compromising worker and public safety.

For California correctional officers (Corrections Standards Authority 2011), standards for entry-level employees were established based on a detailed analysis of job requirements performed jointly with Subject Matter Experts (SMEs) and a study of prevailing on-the-job acoustical conditions. The overall approach was similar to that used by Giguère et al. (2008) for Canadian Coast Guard personnel and Department of Fisheries officers, with the exception that hearing screening criteria were established on the basis of the Extended Speech Intelligibility Index (ESII) from Rhebergen et al. (2006).

## OVERVIEW OF AFFD

Tufts et al. (2009) provide a comprehensive review of the different issues involved in the establishment of hearing standards. Numerous examples are drawn from the military environment, where adequate functional hearing abilities are an essential requirement (e.g. detection of footsteps, target identification, understanding commands during combat, etc.). Hearing fitness standards are also important and in use in many other civil and governmental organizations. In a detailed table summarizing various hearing standards used in the USA, the authors provide examples from the Federal Mine Health and Safety Series, the Federal Air Traffic Control, and the Michigan State Police, to name a few. Similarly, threshold-based hearing standards are also in effect in Canada for military personnel, police officers and railway workers; however, a few pan-Canadian organizations [Department of Fisheries and Oceans Canada (DFO) and the RCMP)] have adopted screening measures that do not rely solely on the audiogram.

The final decision pertaining to an employee's ability to perform the job in a safe and secure manner should be based on 1) results of AFFD testing, 2) job requirements, 3) amount of on-the-job experience, 4) legal considerations, and 5) the needs of the organization (Tufts et al. 2009). With regards to legal considerations, one can cite an example involving threshold-based DFO standards being successfully challenged in court by an employee with unilateral hearing loss. The Canadian Human Rights Tribunal ruled that the organization should revise their hearing standards. Details of this major revision of standards were presented at the last ICBEN meeting (Laroche et al. 2008) and also published in both Laroche et al. (2003) and Giguère et al. (2008). In establishing new criteria, the job requirements and needs of the organization were taken into account by involving SMEs from the beginning of the project.

In most cases, hearing abilities required for the safe performance of hearing-critical jobs include sound detection, sound recognition, speech perception in noise and sound localization. However, a detailed analysis of the various standards used across the USA (Tufts et al. 2009) and elsewhere reveals that most are still based purely on the audiogram. Unfortunately, except perhaps for sound detection in quiet, the audiogram is generally a poor predictor of hearing abilities required on the job. Accordingly, the development of AFFD protocols that are valid, reliable, and consistently and appropriately implemented is of paramount importance.

A good starting point in the development of such protocols is a thorough job analysis to identify hearing-critical tasks, the importance of such tasks, the environment and conditions in which these tasks must be performed, and the minimal performance level required by the employer. This job analysis must be carried out jointly by SMEs from the organization and specialists in the field of hearing. The former group can describe the conditions in which hearing-critical tasks are performed, while the latter group can help identify the underlying functional hearing abilities required for each task as well as the screening tests that can be used to measure these abilities. Two different approaches to AFFD screening are recommended; real-world simulations and the use of valid screening tests. Real-world simulations involve a substantial amount of time and money on an ongoing basis, but may be required in particular situations. In such cases, one must ensure that realistic on-the-job conditions are provided when administrating the test protocol, and that valid normative data have been established. For the second approach, one must ascertain the predictive validity of the screening tests and screening criteria for the given workplace, which will require a substantial amount of experimental work upfront.

Tufts et al. (2009) offer some directions for the future. AFFD test protocols cannot be viewed as "one size fits all" and must be job-specific. The authors also emphasize that the "pure-tone audiogram is no longer defensible as the only AFFD test in most cases" (p. 553). In support of this statement they provide an example of soldiers returning from war with traumatic brain injuries due to explosives. Such individuals can present normal audiograms yet complain of difficulties understanding speech in noise.

RCMP STUDY (Vaillancourt et al. 2011)

Over the last few years, the RCMP has been faced with a growing number of police officers requiring the use of hearing aids due to the aging workforce and, possibly, from noise exposure and shooting range training over the course of one's career. Officers are classified into 5 categories of hearing (H1 to H5 with increasing hearing loss) based on their audiogram. When reaching H4, the degree of hearing loss is considered large enough that the officer is assigned to "non-operational" duties and a hearing aid trial is recommended. With hearing aids, reclassification to H2 (fully operational) or H3 (operational with certain restrictions) is possible. In light of the high number of officers with H4 classification or above and the costs of training RCMP officers for pan-Canada duty, the organization is seeking to implement alternative strategies that allow more officers to be reintegrated into the workforce. Vaillancourt et al. (2011) report on the assessment of RCMP officers wearing hearing aids. The purpose of the study was to quantify individual performance in different domains of hearing identified as necessary components of AFFD for this organization, and to document the benefits, if any, of hearing aids for functional hearing. The data were to help RCMP in making more informed decisions regarding AFFD in officers wearing hearing aids.

The proposed new AFFD protocol includes unaided and aided measures of speech recognition in quiet and in noise using the Hearing in Noise Test (HINT) (Nilsson et al. 1994; Soli & Wong 2008), and sound localization in the left/right and front/back horizontal planes. Sixty-four officers with hearing thresholds exceeding hearing class H3, 57 of which owned hearing aids, were identified and selected by the RCMP to take part in the study.

Based on individual test results, 49 % of officers were reclassified from non-operational status to operational with limitations and restrictions on the basis of adequate functional abilities for speech perception and sound localization, either with or without their hearing aids. As the need for pass/fail criteria was urgent to deal with the growing number of police officers required to wear hearing aids, the 5$^{th}$ percentile of performance by normal hearing individuals on measures of speech perception in noise and sound localization was deemed acceptable prior to the establishment of job-specific criteria for the RCMP. A similar approach was used by Goldberg (2001) for the California Commission on Peace Officer Standards and Training. For speech perception in quiet the criterion was set at 40 dBA, ensuring that RCMP members are able to understand various levels of speech, including whispered speech, at typical conversational distances.

Individual data relative to the functional criteria are summarized in Table 1. The Speech reception threshold (SRT) corresponds to the average presentation level of the sentences presented in Quiet, whereas the Noise Composite score [(2×NF + NR + NL)/4] is used to represent overall functional ability for speech perception in noise under binaural listening conditions (NF = Noise Front; NR = Noise Right; NL = Noise Left). The results highlight a key issue for the design and fitting of hearing aids. While they can provide benefits in speech recognition hearing aids can significantly hinder front/back localization abilities, as shown by the following key results:

- 13 out of 17 (76 %) officers who did not meet the speech in quiet criterion passed with hearing aids. Hearing aids are therefore beneficial to improve speech in quiet most of the time.
- 10 out of 30 (33 %) officers who did not meet the noise composite criterion passed with hearing aids, suggesting that research and development are still needed to improve speech perception in noise with hearing aids;
- Only 1 of 21 officers who did not meet the criterion for front/back localization passed aided, highlighting a limited benefit of hearing aids. Of even greater concern, 16 out of 36 (44 %) officers who initially met the criterion for front/back localization failed aided. Because they limit the frequency bandwidth to about 5 kHz, hearing aids seem detrimental for sound localization in the front/back dimension, which relies on high-frequency information above 5 kHz.

**Table 1:** Summary of unaided vs aided performance in RCMP officers wearing hearing aids (N=57)

| Task | Performance measure | Aided outcome | Unaided outcome | |
|---|---|---|---|---|
| | | | Pass | Fail |
| HINT | SRT in Quiet | Pass | 40 | 13 |
| | | Fail | 0 | 4 |
| | Noise Composite | Pass | 27 | 10 |
| | | Fail | 0 | 20 |
| Localization | # of L/R errors (Behind) | Pass | 53 | 2 |
| | | Fail | 0 | 2 |
| | # of F/B errors (Side) | Pass | 20 | 1 |
| | | Fail | 16 | 20 |

Additional analyses also indicated that hearing thresholds were poor predictors of functional abilities for speech in noise ($r^2$ = 0.26 to 0.33) and sound localization ($r^2$ = 0.03 to 0.28). Only speech in quiet ($r^2$ = 0.68 to 0.85) was predicted adequately from threshold data.

Results show that hearing aids can considerably affect front/back localization abilities in some individuals. Moreover, speech understanding in noise and sound localization abilities were poorly predicted from hearing thresholds, demonstrating the need to specifically test these abilities, both unaided and aided, when assessing AFFD. Finally, the authors conclude that further work is needed to develop empirically-based hearing criteria for the RCMP. The current AFFD criteria used are called “interim criteria” as the hearing-critical tasks and the environmental conditions in which these tasks are performed have not yet been identified. Such criteria will need to be validated and refined using an approach similar to that used by the Corrections Standards Authority (2011), as described below.

Finally, as RCMP members were tested using their own hearing aids, fitted and adjusted independently from the study, makes, models, styles and settings covered a wide range, making it difficult to identify the optimal characteristics of hearing aids for the performance of hearing-critical tasks. Further work is needed to identify best practices in hearing aid fittings for optimal functional hearing abilities.

CORRECTIONS STANDARDS AUTHORITY (CSA 2011)

Public protection and safety issues are constant concerns for Correctional Officers who must prevent escape, quell riots, and protect the public and other custody personnel in detention establishments. A Correctional Officer's job requires a high degree of physical and sensory abilities, including hearing. Any hesitation, reluctance, or inability to fully engage in a critical and potentially life-threatening situation caused by inability to hear could trigger a sequence of events that could have significant, even fatal, consequences.

The hearing standard for entry-level California Correctional Officers was last updated in 1992. The recent strategy put in place to develop new screening measures consists of four major elements:

1) Identification of hearing-critical job functions performed by Correctional Officers with the help of SMEs;

2) Determination of functional hearing abilities important in the performance of these functions (e.g., speech comprehension, sound detection and recognition, sound localization);

3) Assessment of the impact of the sound environment, especially background noise levels, on the performance of these functions using a methodology based on the ESII model (Rhebergen et al. 2006); and,

4) Selection of valid and reliable screening tests and protocols to predict the necessary hearing abilities.

Figure 1 shows the components of the complete research and development protocol. Because Correctional Officers must defend themselves while wearing protective headgear and other protective equipment during certain adversarial encounters, such as cell extractions and riots, and this protective headgear may interfere with the use of hearing aids, the screening procedure includes an additional step (see Figure 2) while using such headgear or other protective devices.

The main research findings can be summarized as follows:

- Speech communication is a frequently used and demanding job function in the prison environment.
- More than 28 % of the cues for detecting incidents and emergencies are exclusively based on hearing, and another 23 % involve hearing as a critical component.
- Background noise levels in prison environments where Correctional Officers perform hearing-critical job functions ranged from almost 90 dBA at its loudest to 62 dBA at its softest, with average values between about 70 dBA and 85 dBA.
- The likelihood of effective speech communication in prison noise environments for a person with normal hearing ranges from less than 20 % when normal vo-

cal effort is used up to 100 % when shouting at communication distances of about 1 meter or less.

The study demonstrated that measures of speech recognition in noise are better predictors of functional hearing abilities used by Correctional Officers to perform hearing-critical job functions than traditional measures based on audiometric thresholds. A more appropriate and valid test for evaluating the functional hearing ability of applicants for the Correctional Officer position was found to be the Hearing in Noise Test (HINT) (Nilsson et al. 1994; Vaillancourt et al. 2005). The new standard is based on measures of speech recognition in quiet and in a background noise condition that is representative of the levels found in the Correctional Officer's workplace. The screening criterion in quiet is a speech level of 27 dBA or less. In 75 dBA noise, the screening criterion for speech is 71 dBA or less, corresponding to a signal/noise ratio of -4.0 dB or lower. It is interesting to note that this criterion is identical to that used in screening Department of Fisheries and Oceans Canada personnel with the English version of the HINT (Giguère et al. 2008).

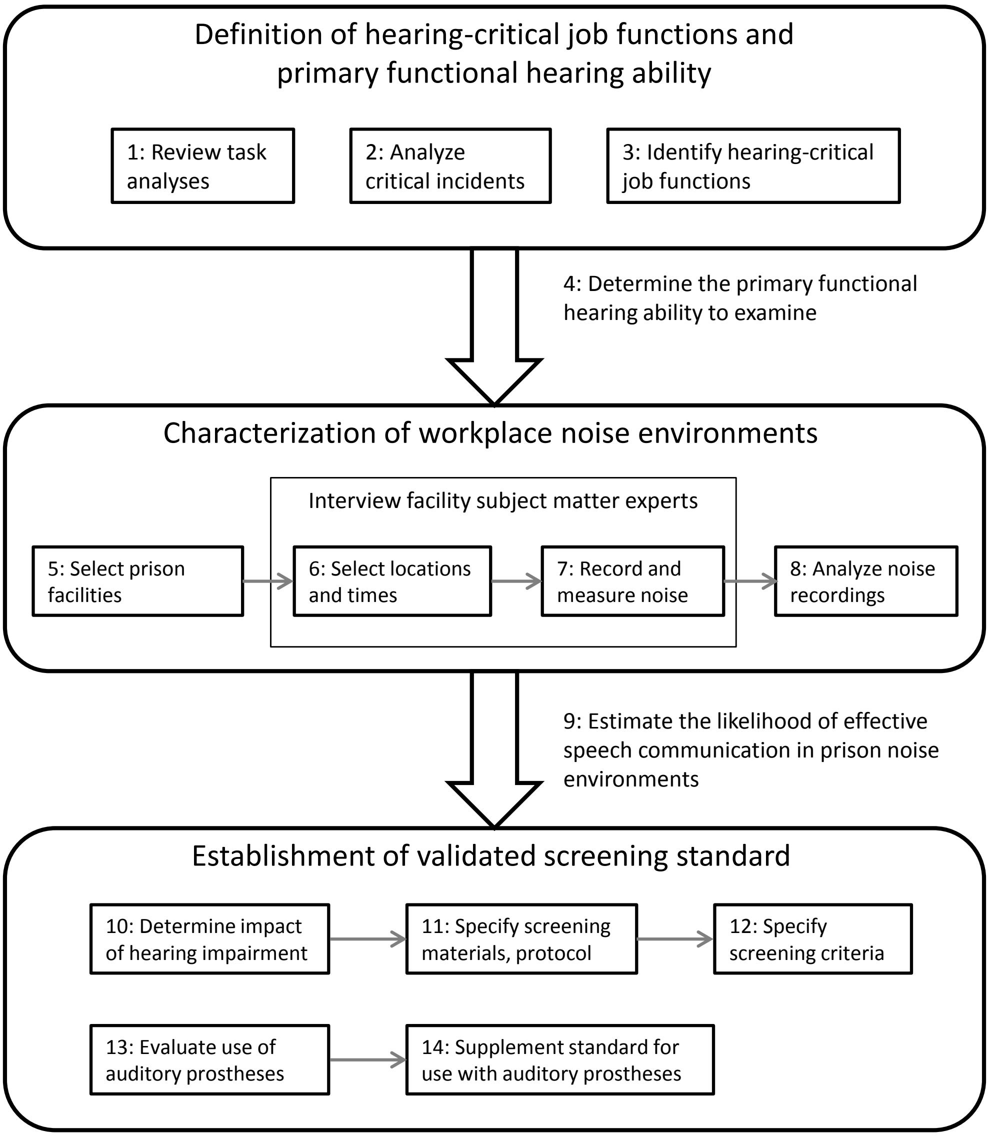


**Figure 1:** Protocol used to establish validated screening standards for Correctional Officers. Reproduced from CSA 2011, used with permission

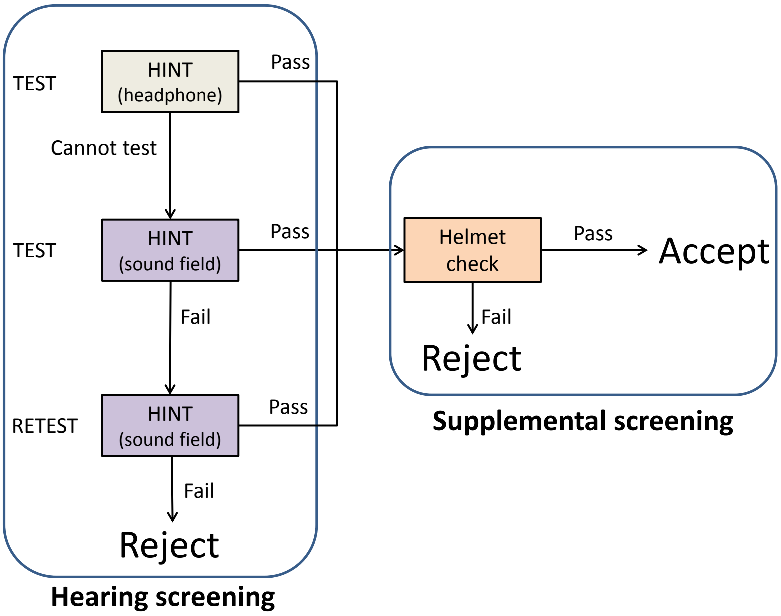


**Figure 2:** Screening protocol including the wearing of helmet or other protective devices. Reproduced from CSA 2011, used with permission

## CONCLUSIONS

The few documents published over the last three years emphasize the need to move beyond the audiogram in the establishment of hearing standards and during AFFD testing. Where hearing-critical tasks must be performed in noisy environments, and where worker or public safety is at stake, valid assessment of the workplace and of the functional auditory abilities must be undertaken, in close collaboration with employers, SMEs, and other experts in audiology and engineering. The examples described above (RCMP, CSA) represent two work environment situations that can also occur in other military and civil organizations. In the case of the RCMP, faced with a significant number of job restrictions among its workforce, functional criteria were immediately needed prior to performing a detailed job analysis and obtaining workplace noise data to establish more definitive criteria. This approach has helped guide the employer in making more informed decisions for individual officers, thereby minimizing the number of experienced police officers being assigned to administrative duties due to elevated hearing thresholds when, in reality, they did not present a significant safety risk based on functional hearing measured.

Further, hearing aids can positively or negatively affect functional hearing abilities, the latter occurring in a significant number of cases for sound localization, and to a lesser extent for speech communication in noise, as measured by the HINT Composite score. Thus, AFFD testing both with and without hearing aids is needed to help the employer determine the most suitable conditions during operational duty in each officer. The CSA example clearly illustrates how a valid AFFD protocol can be proposed when all key players (SMEs, experts, employer) are involved and when the tools used (e.g. HINT, ESII) have been scientifically established. Other organizations are encouraged to use a similar approach to establish criteria that are directly linked to their work environment and job requirements. In some cases, the methodology may need to be adapted to deal with the effects of hearing protectors on auditory performance if used in the workplace, for example through use of speech intelligibility

(Giguère et al. 2010) or alarm detection (ISO 7731:2003, Zheng et al. 2007) models. Further work is needed to be able deal with communication devices and advanced adaptive hearing protection technologies.

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# The perceptual and cognitive aspects of warning sound design

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## INTRODUCTION

Ensuring that an auditory warning is appropriately loud for its environment (i.e. it is neither too loud nor too quiet), localisable, and resistant to masking is a demanding set of challenges. However, even if these issues are successfully resolved, it is still the case that warnings and alarms will not necessarily work simply by virtue of being appropriately loud. In this paper I will outline some warning design issues which are the domain of cognitive psychology, rather than that of acoustics and psychoacoustics. I will demonstrate with some examples.

## LEARNABILITY

In some environments, particularly in healthcare, there are a great many alarms and so the issue of learnability has become important. While there might be an expectation that alarms might require some learning (for example, alarms used in places where there are patients and relatives may require some level of coding), alarms that are too difficult to learn will become an unnecessary burden to staff. There is some evidence to show that alarms taken from different classes of sound are differentially difficult to learn and retain (Leung et al. 1997; Ulfvengren 2003; Keller & Stevens 2004). The factor which seems to underpin the ease with which people can learn sounds is the degree of signal-referent relationship, which is the degree to which the sound (the warning or alarm) is associated with the object or situation which it represents. Petocz et al. (2008) have clarified that this association can come from either physically determined relationships between sounds and objects (for example, the sounds actually made by an object when it is doing the thing one wishes to signal, which in semiotic terms is called a sign) or from learned relationships. An example of the former would be tyres skidding when we are braking violently, and an example of the latter might be a school bell which is associated (by most of us) with the end of school lesson. The best example of learned associations between sounds and objects is, of course, speech. The available studies which are underpinned by the strength of the signal-referent relationship demonstrate that both modern and more traditional abstract alarms are difficult to learn, taking many trials. 'Auditory icons', which are a large group of sounds where there is usually some kind of metaphorical relationship between the sound and its referent (for example, a monkey screech representing 'attack') are much easier to learn, and speech is the easiest of all to learn.

Thus, different types of sounds are easier and more difficult to learn, and this might be an important tool in warning sound design. The UK's Rail Safety and Standards Board (RSSB) has an alarms and alerts evaluation tool with a sound library demonstrating different classes of sounds, what their advantages and disadvantages might be, with suggestions as to how they might be used (http://www.rssb.co.uk/sitecollectiondocuments/pdf/research-toolkits/T326/ index.html).

IEC 60601-1-8 (General requirements, tests and guidance for alarm systems in medical electrical systems, 2006) is an important standard for medical alarms and there has been much debate about the efficacy of the alarms designated in the current standard. One issue pertinent to these alarms (there are more which I will come to later) is that the alarms are tonal and abstract. The evidence would suggest that, as a class, tonal alarms would be difficult to learn and research studies looking specifically at these alarms confirms this to be the case (Wee & Sanderson 2008; Sanderson et al. 2011).

## DIFFERENTIATION BETWEEN ALARMS

Many sets of alarms in specific work contexts (such as medicine, the rail industry, vehicles) suffer from being too similar to one another. Many alarms are still very shrill and high-pitched and do not use the auditory space available for design. There are a number of reasons for this: responders to alarms often have a view as to what an alarm should sound like, and therefore expect alarms to be of a particular design; the process of standardisation tends to force the people who design and specify the alarms into a design niche as uniformity is often either a goal, or a consequence, of the process of standardisation; and the methods of producing and signalling alarms, even in an electronic age, tend to be rather conservative. Thus within a particular alarm set typically only one or two classes of sound might be used from the available range. The range available includes traditional alarm sounds, modern electronic abstract alarms, auditory icons (which can in theory be any type of sound but in all cases there is at least a metaphorical link between the sound and the event it is representing), earcons (Brewster et al. 1992) which are tonal cues capable of representing hierarchical organisation through sound, and speech. In addition to alarm sets usually representing only one of the available classes of sound, many are even more restricting as they often do not explore the range of alarms possible even within a particular design niche or class of sounds.

A key and heavily-cited piece of psychological research is that by Miller (1957) which demonstrates that people are able to learn between five and nine items. Beyond this. remembering new material is a problem for short-term memory. However, this paper also demonstrated that the number of dimensions by which stimuli differ from one another also affects memory for those stimuli. Stimuli which differ over more dimensions are, all other things being equal, likely to be more resistant to forgetting and also easier to learn. This has direct application to the design of alarms, as it suggests that a useful design principle would be to design heterogeneity into alarm sets.

A demonstration of the usefulness of heterogeneity in alarm sets is seen in Edworthy et al. (2011). In this study we took a set of already-designed alarms which were considered in some quarters to be a little problematic, partly because of their number (17 in all) and partly because of their design. We increased the heterogeneity of the alarm set by making small changes to some alarms (for example, within the set there were a trio of alarms with related functions, which were very similar to one another, which we modified to sound more different from one another but were still clearly related) and replacing some abstract alarms with auditory icons. We carried out two studies each for the old set and for our redesigned set of alarms. In the first study in each case, we asked participants to rate the difference between all pairs of alarms and derived a hierarchical tree structure (dendrogram) demonstrating the closeness of the links between each of the alarms in the set. These studies showed that the original set was in general closer in similarity than our redesigned set. There were also some undesirable similarities between alarms with different functions in the old set which were rated as very similar to one another. In the second of the two experiments for each set of alarms, we carried out learning trials. We found that our redesigned set was easier to learn. Thus we demonstrated that increased heterogeneity (which is confirmed by the difference data) led to, or at least is correlated with, ease of learning. This is a useful principle for auditory warning design in general. The two examples below demonstrate how designing heterogeneity into auditory warning sets may be used in practice.

### Train protection warning system

We recently undertook a design project to design an auditory warning to accompany a new standard for Train Protection Warning Systems in the UK (Railway Group Standard GE/RT 8083 Issue 3). The standard is to come into operation in April 2012 and supports a new standard for the visual display associated with this function. One of the key requirements of the project was to design an auditory warning which would not be confused with other alerts and alarms in the train cab. Thus a major task within the project was to carry out a review of alarms and alerts already in the train cab. The review showed that many of the alarms were either high-pitched or extremely high-pitched (above 3 kHz), with short, repetitive pulses; one or two were tonal, with variation in pitch (for example, a C-E-G sequence); there were several 2- or 4-pulse repeating alarms; there were a few telephone-like rings (as both external and internal telephones are used in rail cabs); there were a few modern alarms which appeared to be designed along the principles set out by Patterson (1982); and there were one or two traditional-style warnings (a bell and a horn).

The review of the current alarms therefore showed what kinds of designs were already in use, and where a design niche might lie. The decision was taken to design a 3-pulse unit, relatively low in pitch, with a frequency-modulated pulse. This was because there were no frequency-modulated alarms within the set, there were no 3-pulse units in the alarms surveyed, and there were relatively few low-pitched alarms (though good design practice would suggest that low-pitched alarms are better for localisation, irritation and so on). The entire design process was achieved by iterating the design through meetings with a steering committee, who approved the actual design as well as the design remit.

Although the project involved design rather than extensive testing, our research and design projects allow us to predict with confidence that the TPWS alarm will be easily recognisable and stand out from the set of alarms in the train cab. Of course, if there were several frequency-modulated alarms already within the set typically used in the cab, this would be a bad design decision. Thus taking this approach to alarm design has to be case-driven and design decisions depend on what alarms are already used in that environment. Of course, there are some absolute principles of good auditory warning design (e.g. Patterson 1982; Edworthy et al. 1991; Watson & Sanderson 2007) which should be adhered to regardless of the set of alarms as a whole. However, the specific alarm context provided by other alarms in the same environment needs to be taken into account. Heterogeneity within an alarm set is a useful goal.

**IEC 60601-1-8**

The international standard on medical equipment alarms was mentioned earlier. This is currently under review, and part of the review concerns the design of the actual alarms in use. The standard precedes an earlier standard, for which there was considerable objection to the specified alarms, which were designed according to Patterson's principles (1982, demonstrated in Patterson et al. 1986). Both the current standard and the earlier one used what are effectively tonal alarms. The Patterson et al. alarms were in fact intended to portray Patterson's design principles based on the construction of a pulse containing acoustic information necessary for localisation, the construction of a short burst of sound akin to a melody, and the construction of complete warnings through repetition of bursts at different levels of loudness, speed and pitch to signify different levels of urgency. However, they were thought of by receivers as melodies. The newer alarms, the ones currently supporting the standard, are considerably more homogeneous than the Patterson et al. alarms, in that they all have the same number of pulses and each conform to a regular and standardised temporal pattern. Specifically, the medium urgency version of the alarms has three pulses and the urgent version consists in each case of the medium priority alarm plus the addition of two pulses. We would predict that this more homogenous set of alarms should be harder to learn than the previous set simply because there is less for the learner to use in order to differentiate between them. A recent study by Sanderson et al. (2011) which compares the earlier set with the current set, as well as a revised new set, shows that all three sets are relatively difficult to learn. This is not surprising, as the research literature shows that tonal alarms are difficult to learn. The results also demonstrate that the newer alarms are more difficult to learn by non-musicians, but that the Patterson et al. alarms do not disadvantage non-musician learners. We can assume that because there is so little variation in the newer set of alarms, only those with special knowledge and ability to attend to small variation in melodic structure (i.e. musicians) can adequately use the cues that differentiate between the alarms. Thus, a narrow design envelope seems to have compromised the learnability of the alarms associated with IEC 60601-1-8. A broader design envelope would seem to be a partial solution to this problem when the alarm sets are redesigned.

Although the broadening of the design envelope seems to help in alarm differentiation and learnability, there are many other issues which need to be borne in mind if this regime followed. For example, listeners expect alarms to have particular attention-getting qualities and there may be some sounds which simply do not work in this way for acoustic or other reasons. The degree to which sounds can function as alarms might interact with the nature of the signal-referent association. For example, alarms with low signal-referent associations may need to sound 'alarm-like', but those with high signal-referent associations may not need to sound 'alarm-like'. We respond to sounds in our environment all of the time in (usually) an appropriate manner, so there is no reason to suppose that we would respond any differently to alarm sounds with strong signal-referent relationships. Sounds with strong signal-referent relations are, almost by definition, either environmental sounds or abstract sounds which are very familiar to us.

## FALSE ALARMS

The issue of false alarms is probably the most prevailing current problem with alarms, particularly in the medical arena. This is particularly true in areas where complex information is being presented and sometimes monitored by the apparatus which presents the alarms. In the medical arena, false alarms sound all the time and there are many different causes such as setting alarm thresholds too low or conservatively; the equipment or the patient falsely triggering an alarm because of some state which cannot be avoided, but which is not important in that context; and medical and other interventions which trigger the alarms (Imhoff & Kuhls 2006). There is consequently a burgeoning of practical protocols aimed at reducing the number of alarms in several medical spheres (e.g. Keller et al. 2011) which have proved successful.

One important source of false alarms is the way the parameters which are being monitored relate to the alarm and its triggering. Ultimately, the success of an alarm system in this type of application can only be as successful as the algorithm underlying the information flow from the patient, to the monitor, and to the recipient of the alarm. Imhoff & Kuhls (2006) describe a number of algorithms which may be used, but report that the use of these algorithms is rather spasmodic in practice. Herein lies an important issue for the alarm designer. No matter how good the design, the efficacy of the alarm will always be undermined by a high false alarm rate, as high false alarm rates leads to high scepticism about the reliability of the underlying alarm system (Bliss et al. 1995; Bliss & Dunn 2000). For example, there is ample research literature demonstrating how the perceived urgency of alarms can be varied, in order to allow mapping between the urgency of the alarm and the urgency of the situation being signalled (e.g. Edworthy et al. 1991; Hellier et al. 1993). The extent to which this can be achieved effectively is necessarily restricted by the efficacy of the underlying alarm algorithms.

## FUTURE DIRECTIONS

Considerable research and knowledge on auditory processing and auditory cognition in relation to alarms and auditory warnings has been gained over the last few years. Little of this appears to have filtered through to practice and application, though there are examples which demonstrate the principles which flow from these findings. Alarms and auditory warnings problems are becoming increasingly salient to those in a position to change policy and practice, in particular in the medical arena. The increased interdisciplinary effort now being aimed at alarm and auditory warning practice should help the flow of expertise from one area to another, which is long overdue.

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# Communication in noise for aging adults: interactions of auditory, cognitive and social factors

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## INTRODUCTION

It is well known that many older adults report having disproportionate difficulties understanding speech in noise compared to younger adults (CHABA 1988). These reports are made even by those who have little difficulty understanding in quiet and who have audiograms considered to be normal for their age and gender (ISO 7029-2000) and within normal clinical limits up to 4 kHz. Over the last two decades, much has been learned about specific age-related differences in auditory and cognitive factors that may account for their difficulties in noise (Gordon-Salant et al. 2010).

The main thesis of the present paper is that, in addition to considering the now well-researched age-related differences in auditory and cognitive processing that play a role in communication in noise by aging adults, it is also important to consider socio-emotional factors that can influence listening and how older adults may differ from younger adults in coping with listening difficulties in noise. An appreciation of the connections between the trio of psychological domains shown in Figure 1 promises to offer new insights into the causes and consequences of the communication problems that older adults have in noise even if they have little audiometric loss.

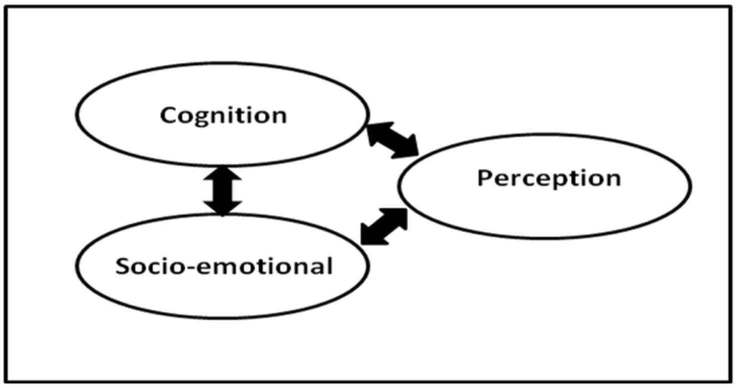


**Figure 1:** Trio of domains contributing to age-related differences in communication in noise

To explore these connections, preliminary evidence from four studies examining a variety of measures will be presented. The first study uses behavioral testing to examine the relationship between psychoacoustic measures and speech and music perception in older adults. The second set of studies involves the use of jittering as a simulation of auditory aging to determine if this type of temporal distortion can shift the performance of younger adults to mimic that of older adults. The third study examines age-related differences in self-reported listening difficulties. The fourth study explores the relationship between behavioral and self-reported measures of hearing with behavioral measures of memory and self-reported stigma and mood.

## STUDY 1: AUDITORY AGING FACTORS AFFECTING SPEECH AND MUSIC

Over the last two decades, age-related differences in the auditory temporal processing of fine structure and envelope cues have been found (for a review see Pichora-Fuller & MacDonald 2008). To study the relationship between age-related differences across various measures of auditory temporal processing, we tested 48 older adults (mean age = 72 years, range 66 to 81) who had pure-tone thresholds within normal clincial limits ($\leq$ 25 dB HL from .25 to 3 kHz) using a battery of tests. The test battery was compromised of audiologic (including high-frequency audiometry and oto-acoustic emissions (OAEs)), psychoacoustic (including measures of frequency difference limens for .5 and 2 kHz tones and for voice fundamental frequency ($F_0$), gap detection thresholds for .5 and 2 kHz tone-pips and for within- and between-channel speech and non-speech markers, and amplitude modulation detection thresholds), and word tests (including monosyllabic words presented in babble and distorted by vocoding, time-compression and jittering).

The pattern of correlations suggests that there are three main factors: high-frequency pure-tone thresholds (HFPTA for .4, .6 and .8 kHz), envelope coding (gap detection and amplitude modulation thresholds), and periodicity coding ($F_0$). There were no strong correlations between pure-tone measures and temporal measures nor between temporal measures related to periodicity coding and those related to envelope coding. Age was significantly correlated with HFPTA, as well as with psychoacoustic measures related to envelope coding, including gap detection (especially between-channel gap detection with a broadband noise as the leading marker and a 500-Hz tone as the lagging marker) and amplitude modulation thresholds. Word recognition with competing multi-talker babble at -15 dB SNR was significantly correlated with the HFPTA and standard PTA (.5, 1 and 2 kHz) as well as with amplitude modulation threshold; however, a regression analysis showed that the HFPTA was the dominant factor related to speech in noise accuracy. Importantly, in a subsequent analysis that divided the participants into two groups, those with normal OAEs (N = 24) and those with abnormal OAEs (N = 15), it was shown that word recognition in noise was driven by amplitude modulation for the group with normal OAEs ($p = .02$) and by HFPTA for the group with abnormal OAEs ($p = .07$). Furthermore, in a sequel experiment examining the perception of music tonality, the factor which best predicted performance was $F_0$ (Russo et al., submitted).

These findings suggest that most (but not all) older adults with relatively good audiograms have sub-clinical auditory temporal processing deficits at various levels, including periodicity coding, onset-offset coding of gaps, and coding of envelope fluctuations over time. Each of these types of temporal processing seems to play a specific role depending on the type of signal, with $F_0$ contributing to the perception of music tonality while amplitude modulation and HFPTA contribute to word recognition in competing babble. In addition, the type of pathology influences the relative contributions of auditory abilities, with audibility being the dominant factor for those with abnormal OAEs, but with amplitude modulation being more important for those with normal OAEs, presumably because the former group have more outer hair cell damage than the latter group who may have more neural degeneration.

## STUDY 2: USE OF TEMPORAL JITTER TO SIMULATE AUDITORY AGING

The prevalence of high-frequency hearing loss increases markedly with age, with the most typical causes being damage to the outer hair cells (OHC) and/or to reductions in the endocochlear potential (Mills et al. 2006); however, neural presbycusis can occur independent of the typical sorts of cochlear damage and without necessarily manifesting as elevated audiometric thresholds (e.g. Frisina et al. 2001; Walton 2010). At least for older adults with good audiograms, age-related differences in temporal processing seem likely to explain the particular difficulties they experience when listening in noise (Pichora-Fuller & Souza 2003). Such differences in temporal processing may be explained more by the neural changes in the aging auditory system than to changes in the OHCs (see also Kujawa & Liberman 2006). This view could explain why in Study 1 the word recognition scores in babble for older adults with good OAEs were driven by measures of temporal processing whereas they were driven more by HFPTA for those with abnormal OAEs.

In general, there is often a confound between age and the degree of audiometric threshold elevation. It is difficult to control both age and hearing loss experimentally because, even if the audiograms of younger adults are similar to the audiograms of older adults, there is no guarantee that they have the same underlying pathology. Conversely, if younger adults with good hearing are compared to older adults with good hearing, there is no guarantee that the older adults do not have neural damage that is not well indexed by the audiogram. One way to contend with this dilemma is to try to simulate the effects of the temporal aspects of auditory aging by distorting signals and presenting them to younger adults with normal hearing in an attempt to render their performance similar to that of older adults. In this way the consequences of signal properties to performance can be evaluated using a within-subjects design.

In general, older adults typically require a 3 dB SNR advantage compared to younger adults to achieve 50 % accuracy on word recognition in noise tests (e.g. Pichora-Fuller et al. 1995). When speech was temporal jittered to disrupt the periodicity of the signal, the threshold for 50 % accuracy on word recognition in noise by younger adults shifted by about 3 dB SNR to approximate the performance of older adults (Pichora-Fuller et al. 2007). Furthermore, as well as making younger adults recognize words in noise like older adults, their memory for recognized words was also reduced to match the word recall of older adults when temporal jittering was used to distort the speech, providing support for the claim that reduced memory for words heard in noise may be secondary to the auditory temporal processing problems of older listeners (Brown & Pichora-Fuller 2000). Jittering has also been successful in altering the performance of younger adults to become more like that of older adults on psychoacoustic and speech perception measures; for example, when within-channel gap detection is tested using periodic markers such as tones or vowels, when concurrent vowel identification is tested as a function of the vowel $F_0$ separation, or when the perception of musical tonality is tested. Taken together, these findings suggest that the subtle distortion of periodicity cues in jittered signals presented to younger listeners can affect their performance on psychoacoustic, speech and music tasks in ways that resemble age-related declines in performance. The results also suggest that for certain stimuli in certain tasks there is a connection between periodicity coding and other levels of temporal and cognitive processing.

## STUDY 3: AGE-RELATED DIFFERENCES IN SELF-REPORTS OF DIFFICULTY

Experimental measures of auditory processing shed some light on why older adults may have difficulty when speech is masked or speeded, but the kinds of everyday listening situations that pose a challenge for older adults often involve additional non-auditory demands. Listener may need to focus, switch, or divide attention when there are multiple sound sources. They may need to not only hear, but also understand new information, remember a complex set of instructions, or synchronize the coordinated turn-taking in alternating roles as listener or talker as is required in a conversation.

The Speech, Spatial and Qualities of Hearing Scale (SSQ; Gatehouse & Noble 2004) is a questionnaire developed to measure a listener's self-reported ability to hear in a variety of everyday situations. The SSQ can be used to gain insights into the possible contributions of auditory and cognitive factors to the everyday listening difficulties of older adults. The SSQ was administered to 48 younger (mean age = 18.6 years, range 18 to 22) and 48 older adults (mean age = 70 years, range 64 to 80) (Banh et al., 2011). Significant differences ($p<0.05$) were found on 42 of the 46 questions. Table 1 lists the items for which the greatest age-related differences were observed. These items met the criterion that the younger adults scored at least 1.4 points (on a 10-point scale) higher than the older adults (1.4 = Mean + 1 SD of the between-group item difference scores). The situations that resulted in these pronounced age-related differences required the listener to use temporal processing to segregate voices, to judge the direction of moving sound sources, and to interpret reverberation, as well as using cognitive processing to focus and switch attention to a target voice during conversation. Clearly, both auditory temporal processing and cognitive processing contribute to age-related differences in everyday listening.

**Table 1**. Mean and standard deviation (SD) of the SSQ item scores for younger and older adults

| | | Younger adults | | Older adults | |
|---|---|---|---|---|---|
| Speech hearing items | | Mean | SD | Mean | SD |
| 5 | Talking with one person in continuous noise | 9.1 | 1.1 | 7.5 | 2.1 |
| 7 | Having conversation in echoic environment | 8.7 | 1.3 | 7.1 | 2.0 |
| 8 | Ignore interfering voice of same pitch | 8.3 | 1.3 | 6.8 | 2.2 |
| 9 | Ignore interfering voice of different pitch | 9.1 | 0.9 | 7.2 | 2.1 |
| 12 | Follow conversation switching in a group | 8.7 | 1.3 | 7.1 | 1.8 |
| Spatial hearing items | | | | | |
| 13 | Identify if vehicle is approaching or receding | 9.2 | 0.9 | 7.7 | 1.6 |
| Qualities of hearing items | | | | | |
| 2 | Sounds appearing jumbled | 9.1 | 1.3 | 7.3 | 3.0 |

## STUDY 3: STIGMA AND MOOD RELATED TO SELF-REPORTS OF DIFFICULTY

Beyond the age-related differences in auditory temporal processing and cognitive processing that seem to conspire to make listening in noise more difficult for older adults, it also seems likely that social and emotional factors may modulate their communication performance and the way in which they cope with these difficulties. Hearing problems may exacerbate psychosocial declines in older adults, but conversely, age-related psychosocial issues may aggravate hearing problems.

It is possible that social factors, in particular feelings of age-related stigmatization and low self-efficacy, may exacerbate poor perceptual and cognitive performance, with consequences to listening and communication (Kramer et al. 2002; Kempen et al. 1999). Social psychologists have made significant advances in the measurement of stigma (Kang & Chasteen 2009). Stunning findings from social psychology have shown that behaviors as widely ranging as walking speeds (Bargh et al. 1996) and hearing thresholds (Levy et al. 2006) can be affected by age-related stereotypes (Dijksterhuis & Bargh 2001) and that such effects impact not only non-members of a stereotype-group, but group members as well. “Stereotype threat” refers to the risk of confirming a negative stereotype of a group with which one identifies (Schmader et al. 2008; Steele & Aronson 1994; Steele et al. 2002). For example, the degree to which one holds stereotypic beliefs can negatively impact one’s own memory performance (Beilock et al. 2007; Chasteen et al. 2005; Croizet et al. 2004; Hess et al. 2009; Schmader & Johns 2003). Another potentially important factor is self-efficacy, or the confidence listeners have in their abilities, which also may influence performance, with a relevant domain being speech perception and language comprehension abilities in daily conversational situations (Wingfield & Tun 2007). Self-efficacy has been shown to play an important role in the successful management of numerous health conditions; however, research directly focusing on self-efficacy related to listening abilities is limited (Smith et al. 2011).

To explore the relationships between auditory, cognitive and socio-emotional factors, to date 155 adults (55 years or older) have been tested on a battery of behavioral measures of hearing and cognition as well as self-report measures of their auditory and socio-emotional status. For the present paper, the analysis included two behavioral measures of hearing ability: audiometric thresholds (PTA for .5, 1, 2, and 3 kHz) and word recognition threshold [SNR threshold for 50 % correct word recognition on the Words-in-Noise Test (WIN); Wilson 2003; Wilson et al. 2007)]. There were also two behavioral measures of cognitive ability, a memory free recall test and a screening test for mild cognitive impairment [Montreal Cognitive Assessment (MoCA); Nasreddine et al. 2005]. In addition to the behavioral four measures, there were four self-report measures, two concerning listening, the SSQ and the Listening Self-efficacy Questionnaire (LSEQ; Smith et al. 2011), and two concerning socio-emotional status, The Fear of Aging Scale (FOA; adapted from Sarkisian et al. 2002) and the Profile of Mood States (POMS; McNair et al 1971).

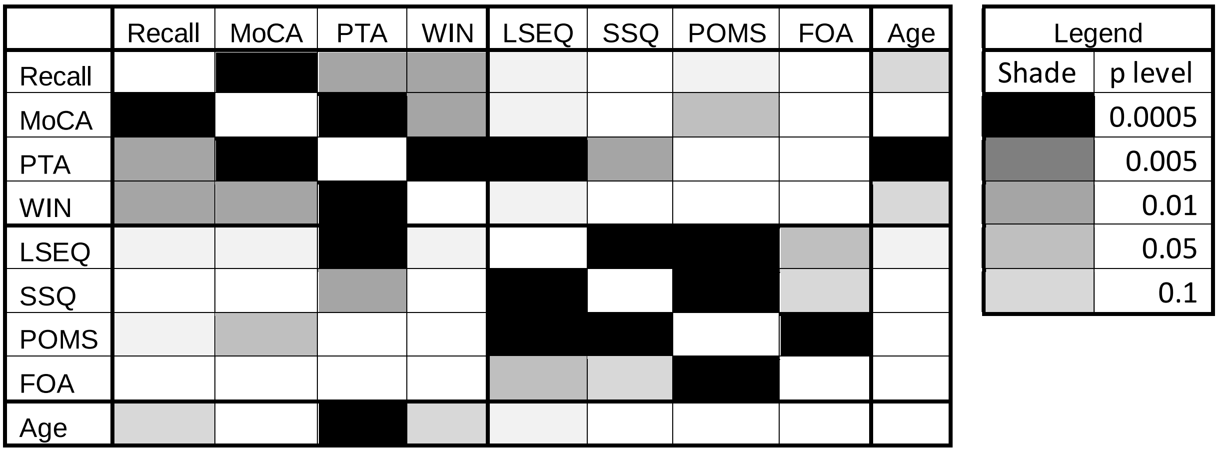


**Figure 2:** Correlations between behavioral measures of memory and hearing and self-reported measures of listening, stigma and mood

Figure 2 shows the correlations between the four behavioral and four self-report measures and age, with the darkness corresponding to the significance level that was reached. Not surprisingly, there were very strong correlations ($p<0.0005$) between the two behavioral tests of hearing ability, between the two behavioral tests of cognitive ability, between the two self-report measures of listening, and between the two self-report measures of socio-emotional status. There were also strong correlations ($p<0.005$) observed between the four behavioral measures. Likewise, there were strong correlations between the four self-report measures. Some significant correlations were observed between the behavioral and self-report measures (e.g., PTA and LSEQ or MoCA and POMS), but these tended to be less robust relationships ($p<0.01$). It is also interesting to note that age correlated significantly only with performance on the two behavioral hearing tests and the behavioral free recall memory test. Thus, there seem to be strong relationships between behavioral measures of hearing and cognition in older adults, as well as between self-report measures of listening and socio-emotional factors; however, the connections between behavior and self-report are relatively weak.

It is difficult to tell from this snapshot of results whether cognitive problems are the cause or the consequence of auditory problems or to tell if self-reported listening ability drives or is driven by socio-emotional factors. It is even more difficult to glean whether the auditory and cognitive behavioral performance of older adults affects their self-reported abilities or whether their self-appraisals influence their actual performance in the short or long term. Nevertheless, it is apparent that the listening difficulties of older adults involve not just auditory but also cognitive factors and that the behavioral changes measured in both auditory and cognitive abilities need to be considered in light of socio-emotional self-perceptions of their abilities.

## SUMMARY

Over the last 20 years, research undertaken to understand why older listeners have disproportionate difficulties compared to younger listeners in noisy situations has advanced our knowledge concerning the nature of age-related differences in temporal processing. Most older adults demonstrate poorer auditory temporal processing than their younger counterparts for various temporal cues ranging from fine structure periodicity cues to cues provided by the ongoing fluctuations in the amplitude envelope of a signal. There seem to be three main types of auditory processing that are interrelated and these are typified by $F_0$ difference limens (periodicity coding), gap detection or amplitude modulation thresholds (envelope coding), and the HFPTA (audibility). The importance of these types of processing can depend on the type of task (speech or music) and whether or not the sub-type of presbycusis involves primarily OHC or neural damage. Nevertheless, evidence from experiments using jittering to simulate the temporal aspects of auditory aging suggest that there may be important inter-dependencies between periodicity coding and the processing of other temporal cues, such as the use of certain envelope cues when there is a gap in a periodic signal. The distortion of the signal caused by jittering also has cognitive consequences insofar as it places a demand on working memory with an observed reduction in working memory span. The role of cognitive factors, especially attention, is also evident when the largest self-reported age-related differences on the SSQ are considered. Finally, there are strong correlations between behavioral measures of hearing and cognition as well as strong correlations between self-reported listening abilities and socio-emotional status, although there are not such strong connections between the behavioral and self-report measures. Thus, the problems that older adults experience when listening in noise involve the trio of auditory, cognitive and socio-emotional factors.

Further research, including longitudinal and intervention research will be required to further understand how auditory, cognitive and socio-emotional aspects of aging interact during listening in everyday life. Now that the connections between auditory, cognitive and socio-emotional factors have been recognized, it remains to determine whether self-appraisal is the cause or the consequence of poorer behavioral performance by older adults and whether auditory declines precede or follow cognitive declines. A better understanding of the chain of effects in the interactions in the trio of psychological domains (perceptual, cognitive and socio-emotional) will enable better prevention and treatment of communication problems in older adults.

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# Effect of noise and reverberation on vocal effort and fatigue of primary school teachers

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## INTRODUCTION

For over one million teachers in Italy their voice is a fundamental work tool and as a result they are thought to be at a higher risk for occupation-related voice disorders than the general population. Vocal emissions seems to be influenced to a great extent by the acoustic conditions of the workplace. In a similar way to the hearing field, literature suggests the use of a dosimetry to measure vocal performances, a field that has not yet been fully explored. The aim of this work is the investigations on the relationships between vocal doses and clinical status, acoustical conditions (noise and reverberation) in the classrooms and subjective evaluations of vocal effort and fatigue. Some vocal dose measures, proposed by Titze & Svec (2003), such as the Vocal Loading Index, the Time Dose, the Distance Dose, the Energy Dissipated Dose and the Energy Radiated Dose, are determined from vocal parameters, in particular fundamental frequency and sound pressure level, collected by the Ambulatory Phonation Monitor (APM 3200) over an entire working day. The clinical examination consisted of a specific anamnesis concerning voice protocol, hearing, functional and professional use of voice (VHI), a logopedic evaluation, Ear, Nose and Throat and phoniatric examination. Two typologies of subjective surveys were administered to the teachers. The first type concerns voice intensity and quality, background noise intensity and physical diseases. The second type consists of 16 questions form aimed at eliciting general information, the experienced vocal symptoms and occurrence and classroom acoustics.

## CASES STUDY

The case studies concern six primary schools in Turin and Beinasco (Italy): the D. Muratori, L. Fontana and R. D'Azeglio schools in Turin, which were built at the end of the nineteenth century, and the E. De Amicis, A. Gramsci and A. Mei schools in Beinasco built in the 70s. All these schools have classrooms which face either onto a quiet street or onto an internal courtyard. The three schools in Turin are historic square-court buildings, while the schools in Beinasco are modern buildings. The classrooms in Turin have vaulted ceiling and a bigger volume in comparison with those of Beinasco. The floor area is about 50 $m^2$ for all the schools, the average height is about 4.5 m in Turin and 3.5 m in Beinasco and the volume ranges from about 240 $m^3$ in Turin and 160 $m^3$ in Beinasco. This study concerns 39 teachers monitored over one, two or three working-days (four hours per day). A total of 66 working-day samples were collected and from these samples 54 traditional lessons were cut and separately analysed. The traditional lesson corresponds to a traditional approach to the class with all the children sitting quietly in front of the teacher who is speaking. Table 1 reports the main characteristics of the investigated teachers, the number of monitored working days, the traditional lessons extracted and the acoustical conditions during traditional lessons.

**Table 1:** Characteristics of the investigated teachers and acoustical conditions during traditional lessons

| Subject | Schools | Age | # of working-days and traditional lessons | RT (s) during traditional lessons | LA90 (dB(A)) during traditional lessons |
|---|---|---|---|---|---|
| 1 | Turin | 38 | 2/- | | |
| 2 | Turin | 43 | 2/- | | |
| 3 | Turin | 37 | 3/2 | 1.1 / 0.4 | 52.8 / 43.9 |
| 4 | Turin | 54 | 3/2 | 1.6 / 0.4 | 51.6 / 44.3 |
| 5 | Turin | 35 | 2/2 | 1.0 / 1.0 | 45.0 / 59.0 |
| 6 | Turin | 39 | 2/- | | |
| 7 | Turin | 40 | 2/2 | 1.2 / 1.2 | 60.6 / 58.6 |
| 8 | Turin | 47 | 2/1 | 0.7 | 54.5 |
| 9 | Turin | 42 | 1/- | | |
| 10 | Turin | 31 | 2/1 | 1.1 | 41.6 |
| 11 | Turin | 34 | 2/2 | 1.3 / 0.4 | 65.0 / 64.3 |
| 12 | Turin | 58 | 2/2 | 0.4 / 1.2 | 43.8 / 51.6 |
| 13 | Turin | 57 | 1/1 | 0.9 | 48.2 |
| 14 | Turin | 57 | 2/- | | |
| 15 | Turin | 54 | 2/3 | 0.9 / 0.9 / 0.4 | 46.3 / 48.9 / 41.4 |
| 16 | Turin | 59 | 2/2 | 1.3 / 0.4 | 50.9 / 42.7 |
| 17 | Turin | 35 | 2/- | | |
| 18 | Turin | 39 | 1/1 | 0.5 | 50.4 |
| 19 | Turin | 27 | 1/1 | 0.7 | 54.8 |
| 20 | Turin | 37 | 1/2 | 0.7 / 0.7 | 53.9 / 50.3 |
| 21 | Turin | 56 | 1/1 | 0.5 | 54.4 |
| 22 | Turin | 48 | 1/1 | 1.1 | 54.3 |
| 23 | Beinasco | 46 | 1/1 | 0.8 | |
| 24 | Beinasco | 34 | 2/1 | 0.8 | 57.5 |
| 25 | Beinasco | 33 | 2/1 | 0.8 | 51.9 |
| 26 | Beinasco | 43 | 1/1 | 0.9 | 52.5 |
| 27 | Beinasco | 49 | 1/1 | 0.8 | 54.0 |
| 28 | Beinasco | 56 | 2/3 | 0.7 | 44 |
| 29 | Beinasco | 59 | 2/2 | 0.8 / 1.1 | 51.1 / 49.2 |
| 30 | Beinasco | 38 | 2/2 | 0.7 / 0.7 | 45.8 / 54.5 |
| 31 | Beinasco | 47 | 2/2 | | 44.3 / 54.4 |
| 32 | Beinasco | 40 | 2/2 | 0.8 / 0.8 | 50.0 / 48.3 |
| 33 | Beinasco | 52 | 2/2 | 0.8 / 0.9 | 62.8 / 57.5 |
| 34 | Beinasco | 55 | 2/1 | 0.7 | 42.6 |
| 35 | Beinasco | 58 | 2/2 | 0.9 / 0.9 | 46.3 / 63.6 |
| 36 | Beinasco | 54 | 2/1 | 0.7 | 46.6 |
| 37 | Beinasco | 48 | 2/3 | 0.9 / 0.9 / 0.9 | 56.0 / 43.0 / 49.6 |
| 38 | Beinasco | 34 | 1/2 | 0.9 / 0.9 | 45.1 / 46.6 |
| 39 | Beinasco | | -/1 | 0.8 | 52.6 |

## SURVEY METHOD

The research, which involves monitoring the vocal performance of primary school teachers and giving teachers a clinical examination, has the aim of detecting the vocal parameters that can be used to assess vocal fatigue and voice recovery in primary school teachers. This is pursued through the investigation of the relationships between vocal parameters and clinical status, vocal parameters and acoustical conditions (noise and reverberation) in the classrooms, vocal parameters and subjective evaluations of vocal effort and fatigue. The adopted protocol has four parts: evaluations of the clinical status of the teachers' voice; measurements of the vocal parameters; subjective surveys; measurements of the acoustical parameters in the classrooms.

## EVALUATIONS OF THE CLINICAL STATUS OF THE TEACHERS

Of the 39 teachers, 32 underwent a clinical examination. This consisted of a specific anamnesis concerning voice protocol, hearing, functional and professional use of voice: the Voice Handicap Index (VHI); a logopedic evaluation related to the respiratory function and voice restoration (GIRBAS Scale) proposed by Dejonckere et al. (1996), Ear, Nose and Throat and phoniatric examination, performed with laryngo-videostroboscopy. Approximately 41 % of the examined subjects showed no sign of disease, while 59 % presented subjective and/or objectively measured pathological symptoms.

## MEASUREMENTS OF THE VOCAL PARAMETERS

Before starting the working day each teacher was supplied with the Ambulatory Phonation Monitor (APM 3200), which is composed of an accelerometer positioned on the talker's neck, below the glottis, and an acquisition device that processes the accelerometer signal. In addition to providing the phonation time, this device also provides the fundamental frequency, and, after calibration, an estimation of the sound pressure level at a distance of 12 cm on-axis from the talker's mouth, both of which are sampled every 50 ms. Calibration is carried out by means of a reference microphone, in order to correlate the skin acceleration level to the sound pressure level. Five different vocal dose measures, proposed by Titze & Svec (2003), are used as indicators of vocal effort and the exposure of the vocal fold tissue to vibrations. These are obtained from the phonation time, the fundamental frequency ($f_0$) and the sound pressure level ($SPL_{m,@1m}$.). Furthermore the standard deviation of SPL (SPLsd) and $f_0$ ($f_0$sd) was evaluated. Vocal doses were measured on 39 teachers (4 males and 35 females) over one, two or three different working days, divided in two half working days (125 samples, 12 for males and 113 for females). The fundamental frequency is significantly influenced by the talker's gender, so the doses were analyzed separately for male and female subjects. In order to compare the different teachers the doses were normalized to the phonation time. The first step was to identify the statistical distribution of each dose and parameter ($D_t$%, $D_{d\_norm}$, $D_{e\_norm}$, $D_{r\_norm}$, $SPL_{m,@1m}$., $f_0$, SPLsd, $f_0$sd), and the possible systematic factors of influence, such as gender and age. All the doses follow a normal distribution except for $D_{d\_norm}$, $D_{e\_norm}$, $D_{r\_norm}$. These doses were transformed in Level Doses with a lognormal function. Table 2 shows the mean value, the uncertainty of the mean (JCGM 100 (2008)) and the robustness coefficients (*r*) (ISO/IEC Guide 43-1 1997) for 39 teachers, divided for males and females, over different half working-days (125 samples) of the doses and parameters. When *r* is higher than 1, the randomness of the parameters can be considered acceptable.

**Table 2:** Mean values, uncertainty of the mean and robustness coefficient of 39 teachers over different half working days (125 samples) of Dt%, Dd_norm, De_norm, Dr_norm, SPLm,@1m., $f_0$, SPLsd and $f_0$sd

| Parameter | Female (113 samples) | | | Male (12 samples) | | |
|---|---|---|---|---|---|---|
| | Mean | U | r | Mean | U | r |
| $D_t$% / m/s | 25.5 | 1.38 | 18.3 | 25.9 | 3.71 | 6.98 |
| $LD_{d\_norm}$ / dB | 66.2 | 0.93 | 71.0 | 63.6 | 1.24 | 51.15 |
| $LD_{e\_norm}$ / dB | 60.7 | 1.91 | 31.6 | 68.7 | 2.51 | 27.32 |
| $LD_{r\_norm}$ / dB | 70.5 | 5.10 | 13.8 | 51.6 | 12.26 | 4.22 |
| $SPL_{m,@1m}$ / dB | 66.4 | 2.08 | 31.8 | 65.8 | 2.68 | 24.59 |
| $f_0$ / Hz | 238.7 | 4.46 | 53.4 | 150.3 | 9.62 | 15.63 |
| SPLsd/ dB | 1.75 | 0.05 | 29.9 | 1.6 | 0.13 | 13.19 |
| $f_0$sd / Hz | 5.36 | 0.15 | 33.9 | 3.4 | 0.35 | 10.06 |

## MEASUREMENTS OF THE ACOUSTICAL PARAMETERS IN THE CLASSROOMS

The impulse response was measured in each classroom using a balloon pop as impulse source. From this measurement, it was possible to obtain the reverberation time using the backward integration technique as suggested by ISO 3382-2 (2008). The ambient noise and speech level were monitored continuously during the working day, using a sample period of 1 s, positioning a sound level meter close to the teacher's desk. The frequency distributions of the levels can be used to estimate the noise level close to the teacher during speech, as suggested by Hodgson et al. (1999). A mixture of two normal distributions can be fitted to each histogram of the combined A-weighted overall levels. One distribution identifies the noise levels ($L_{N\_Hist}$) and the other the teachers' voice levels. One problem encountered in the present study with this technique is the randomness of children activity noise in primary schools, whose levels are difficult to separate from other source levels. In order to overcome this problem, the measurement interval was limited to only lessons with children sitting at their tables and listening to the teacher speaking. The overall A-weighted background noise levels were estimated using the A-weighted percentile levels ($L_{A90}$) from the full sample. Table 3 lists the mean values, uncertainty of the mean of $SPL_{m,@1m}$, $L_{N\_Hist}$, $L_{A90}$, and $RT_{m,500-2k}$ obtained in Turin and Beinasco, respectively. From this analysis, data from one classroom in school Fontana and all the school D'Azeglio were not considered because acoustically treated (Astolfi et al. 2011). The only significant difference between the two groups is among reverberation times.

**Table 3:** Mean values, uncertainty of the mean and p-values of $SPL_{m,@1m}$, $L_{N\_Hist}$, $L_{A90}$, and $RT_{m,500-2k}$ obtained in Turin and Beinasco. From this analysis data from the reading laboratory in Fontana school and the D'Azeglio school were not considered because acoustically treated.

| | Turin (28 samples) | | Beinasco (26 samples) | | (p-value) |
|---|---|---|---|---|---|
| | Mean | U | Mean | U | |
| $SPL_{m,@1m}$ /dB | 62.1 | 5.53 | 59.2 | 4.11 | 0.44 |
| $L_{N\_ist}$ /dB | 51.8 | 3.20 | 52.4 | 2.38 | 0.77 |
| $L_{A90}$ /dB | 53.2 | 3.59 | 50.4 | 2.25 | 0.18 |
| $RT_{m,500-2kHz}$ /s | 1.13 | 0.12 | 0.82 | 0.04 | <0.01 |

## SUBJECTIVE SURVEYS

In order to find any correlations between the vocal parameters and the perceptions of the teachers' own voice statuses, two typologies of subjective surveys were administered to the teachers. The first type consists of a 4-question form, administered after each teaching activity. It concerns voice intensity and quality, background noise intensity and physical diseases (sore throat, aphonia, raucousness, neck stiffness, headache and general illness). Different teaching activities were performed in periods of around two hours at a time. The second type of survey, consists of a 16-question form aimed at eliciting general information, vocal symptoms experienced with their frequency, and classroom acoustics. It was administered at the end of the working day. Most of the answers referred to a 5-point scale in which each step was labelled from 1 to 5 and the extremes with opposite semantic descriptors.

In the second type of questionnaire the teachers were asked to indicate intensity, disturbance and occurrence of different noise sources, and the frequency of a list of perceived consequences caused by poor classroom acoustics experienced in the classrooms. Noticeable differences between schools in Turin and Beinasco on all the questions ($p<0.01$) were observed. As shown in Figure 1 the trends are similar but the scores show lower values in Beinasco. The following abbreviations are used for the noise sources: STC for “Students Talking in the Classroom,” SMC for “Students Moving or shuffling in the Classroom,” STNC for “Students Talking in the Neighbouring Classrooms,” SMNC for “Students Moving or shuffling in the Neighbouring Classrooms,” STMCO for “Students Talking and Moving in the COrridor,” TR for “TRaffic,” ONOB for “Other Noise Outside the Building,” and ONIB for “Other Noise Inside the Building.” The list of perceived consequences consists of “Decrease in perception of the students’ questions” (DPQ), “Loss of concentration” (LC), “Headache” (H), “General Illness” (GI).

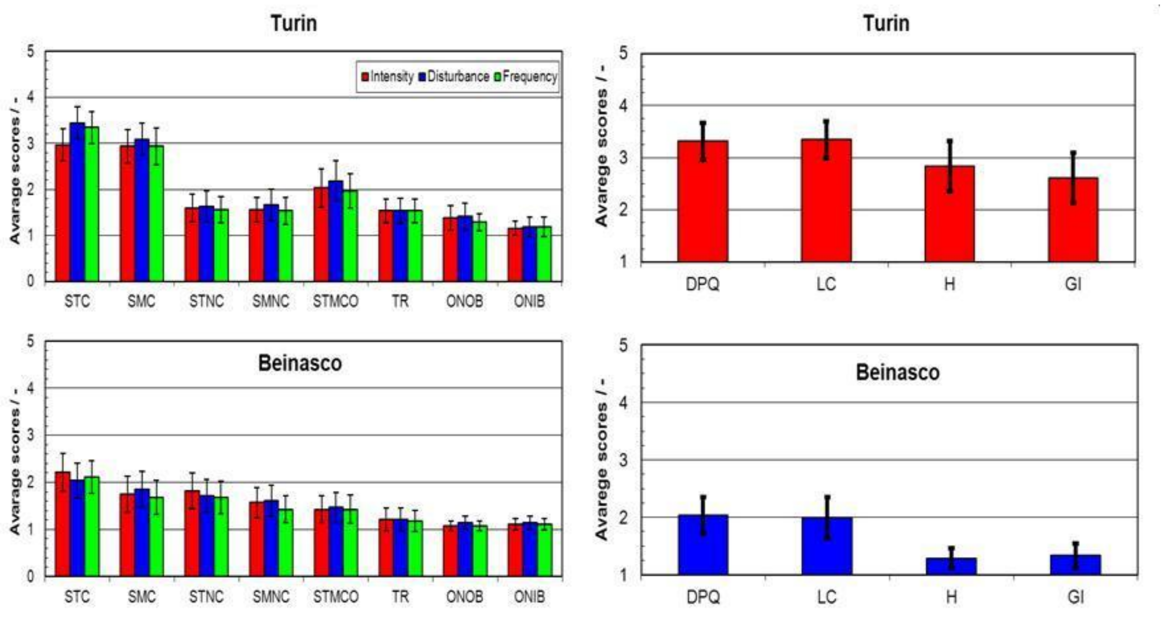


**Figure 1:** Intensity, disturbance and occurrence of different noise sources, and frequency of a list of perceived consequences caused by poor classroom acoustics experienced by the teachers in the classrooms. The five-point scale is from “never” (1) to “very often” (5).

Noticeable differences between schools on the perception of some acoustical factors were observed. The mean scores and the uncertainty of the mean of “Influence of acoustics on teaching” (IAT), “Noise Intensity” (NI), “Noise Disturbance” (ND) (on a 5-point scale from “very low” to “very high”), “Reverberation” (RT) (5-point scale from “very dry” to “very reverberant”), “Speech Comprehension”(SC) (on a 5-point scale from “very badly” to “very well”), “Teachers’ Vocal Effort” (TVE) (5-point scale from “very low” to “very raised”) and the “Acoustical Quality Satisfaction” (AQS) (5-point scale from “very unsatisfied” to “very satisfied”) are shown in Table 4.

In all these cases the ANOVA tests reject ($p<0.05$) the hypothesis of no differences between the perceptions of the two groups, and higher scores are achieved in Turin, where the classrooms are more reverberant, except for the Speech Comprehension and Acoustical Quality Satisfaction. It is interesting to note that differences related to the scores about vocal effort and noise intensity and disturbance perceived by teachers in the two groups of schools are subjectively significant but not objectively.

**Table 4:** Mean scores and uncertainty of the mean of “Influence of acoustics on teaching” (IAT), “Noise Intensity” (NI), “Noise Disturbance” (ND) (on a 5-point scale from “very low” to “very high”), “Reverberation” (RT) (5-point scale from “very dry” to “very reverberant”), “Speech Comprehension”(SC) (on a 5-point scale from “very badly” to “very well”), “Teachers’ Vocal Effort” (TVE) (5-point scale from “very low” to “very raised”) and the “Acoustical Quality Satisfaction” (AQS) (5-point scale from “very unsatisfied” to “very satisfied”) for the schools in Turin (a, b and c) and or the schools in Beinasco (d, e and f), together with p-value from a t-tests for the difference of the mean.

| | Turin (32 samples) | | Beinasco (34 samples) | | (p-value) |
|---|---|---|---|---|---|
| | Mean | U | Mean | U | |
| IAT | 3.09 | 0.34 | 2.14 | 0.37 | <0.05 |
| NI | 2.91 | 0.29 | 2.21 | 0.37 | <0.05 |
| ND | 3.03 | 0.36 | 2.00 | 0.38 | <0.05 |
| RT | 3.19 | 0.42 | 2.04 | 0.31 | <0.05 |
| SC | 2.75 | 0.28 | 3.89 | 0.34 | <0.05 |
| TVE | 3.44 | 0.24 | 3.00 | 0.38 | <0.05 |
| AQS | 2.53 | 0.37 | 3.32 | 0.42 | <0.05 |

## OBJECTIVE ACOUSTICAL MEASUREMENTS IN THE CLASSROOMS AND CORRELATIONS WITH VOCAL PARAMETERS, SUBJECTIVE DATA AND CLINICAL EXAMINATION

Table 1 reports the midfrequency occupied reverberation time and the $L_{A90}$ values in the classrooms investigated during traditional lessons. The number of students in each classroom was between 15 and 25. The reverberation time ranges from 0.5 s, in the L. Fontana reading laboratory, to a mean value of 0.9 s, s.d. 0.2, in the other classrooms. Figure 2 shows the relationships between $SPL_{m,@1m}$ and $L_{A75}$ and $L_{A90}$ values in order to check the Lombard effect. A 0.70-0.72 dB increase of speech level per 1 dB increase of noise level was found. The present result agrees with that of Sato & Bradley (2008) who found a 0.72 dB increase of speech level per 1 dB increase of noise level in primary school classrooms. Figure 3 shows the relationship between $f_{0,mean}$ and $L_{A90}$. The fundamental frequency increases with the increasing in background noise at a rate of 1.2 Hz/dB.

A correlation matrix has been calculated in order to obtain the most significant correlations ($p<0.01$) between the subjective scores expressed after each teaching activity and the acoustical and vocal parameters. “Voice intensity” is strongly correlated with $SPL_{m,@1m}$ (as shown in Figure 4), and with the three dose levels $LD_{d,n}$, $LD_{e,n}$ and $LD_{r,n}$, while “background noise perceived intensity” with “voice intensity” and with $L_{A75}$ and $L_{A90}$. Furthermore Figure 5 shows the relationship between “background noise perceived intensity” and the mid-frequencies reverberation time. The best fit for this relationship is a quadratic curve, and this means that the noise perception increases with the square of the reverberation time. A correlation analysis was performed between the causes and effects related to the vocal pathology. It necessary to underline that the sample number was not sufficient to analyse the synergy of different causes. The grade of pathology was evaluated in a 6 points scale, from the absence of pathology to the presence of vocal nodules. From this first analysis it is possible to state that the main causes of a vocal pathology are $D_t$%, smoking and genetic predisposition, where $D_t$% represents both the vocal load in temporal terms and the speed of speech.

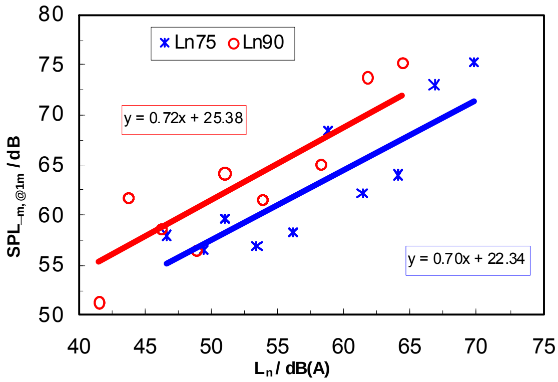


**Figure 2:** Relations between $L_{A75}$ and $L_{A90}$ and $SPL_{m,@1m}$ values during traditional lessons and best-fit regression lines. The $SPL_{m,@1m}$ values were averaged on an $L_n$ intervals of 2.5 dB.

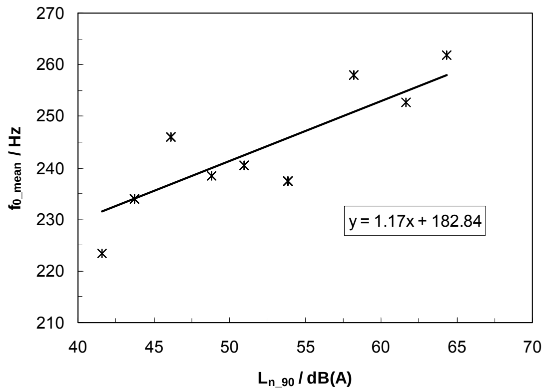


**Figure 3:** Relation between mid-frequency $L_{A90}$ and $f_{0,mean}$ values during traditional lessons and best-fit regression line for female subjects. The $f_{0,mean}$ values were averaged on an $L_{A90}$ intervals of 2.5 dB.

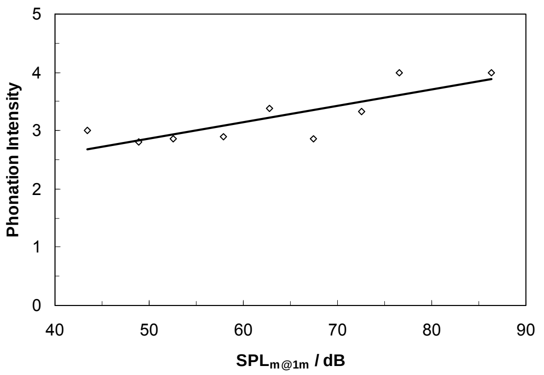


**Figure 4:** Average phonation intensity scores versus measured values of $SPL_{m,@1m}$ and best-fit regression line. The five-point scale is bounded by the words “very low” (1) and “very high” (5). The scores were averaged on an $SPL_{m,@1m}$ intervals of 5 dB.

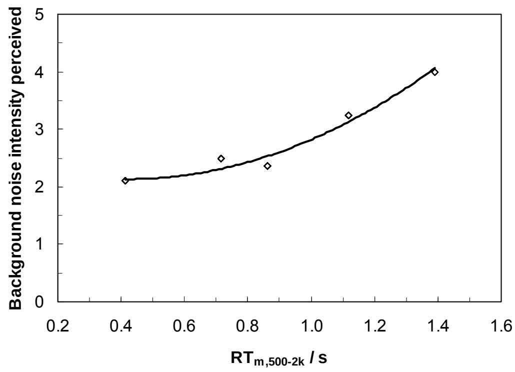


**Figure 5:** Average background noise intensity perceived scores versus measured values of $RT_{mean,500\text{-}2k}$ and best-fit regression line. The five-point scale is bounded by the words “very low” (1) and “very high” (5). The scores were averaged on an $RT_{mean,500\text{-}2k}$ intervals of 0.2 s.

## CONCLUSIONS

From the current data the following main conclusions can be drawn:

- Approximately 41 % of the examined subjects showed no sign of disease, while 59 % presented subjective and/or objectively measured pathological symptoms.
- The mean sound pressure level of the voiced speech at 1 m from the talker’s mouth and the mean fundamental frequency during a full day teaching were re-

spectively 66.2 dB, U 2.08, and 238.7 Hz, U 4.46 for female, and 65.8 dB, U 2.68, and 150.3 Hz, U 9.62 for female.

- ‘Students talking in the classroom’ is judged to be the most annoying, intense and frequent noise source in classrooms.
- The most important consequences of the poor acoustics in all the schools were ‘Loss of concentration’ and ‘Decrease in students question perception’.
- For the two groups of schools, Torino and Beinasco, the subjective assessments about teachers’ vocal effort and background noise intensity are confirmed by the objective measurements of $SPL_{m,@1m}$, $L_{N\_ist}$ and $L_{A90.}$
- A Lombard effect corresponding to a 0.70-0.72 dB increase of speech level per 1 dB increase of noise level was found.
- The fundamental frequency increases with the increase in background noise at a rate of 1.4 Hz/dB.
- The “Perceived voice intensity” increases with the increase of $SPL_{m,@1m}$ and “background noise perceived intensity” increases with the square of the reverberation time.
- The main causes of a vocal pathology are $D_t$%, smoking and genetic predisposition, where $D_t$% represents both the vocal load in temporal terms and the speed of speech.

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# Using cluster analysis to explore how children use semantic cues when listening to sentences presented with a babble noise

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## INTRODUCTION

It is well documented that children require a higher signal-to-noise ratio (SNR) than adults to understand speech in the presence of background noise (Fallon et al. 2002; Picard & Bradley 2001). This difference in speech perception abilities in noise between children and adults has been attributed to developmental factors including, but not limited to, immature auditory system (Fallon et al 2000, 2002; Talarico et al. 2007), language skills (Elliott et al. 1979) and other cognitive functions, such as short term memory (Choi et al. 2008). Because of these developmental factors, variability on speech in noise tests can be expected both within and across age groups. Indeed, according to Leibold & Neff (2007), many studies on speech perception in noise with normal hearing children report large variability. Adult-like performance on perception in noise tasks is generally not reached until 13-15 years of age (Crandell & Smaldino 2000).

The ability to benefit from the linguistic and contextual information counts among the factors that have been studied to explain the difference between children and adult performance while listening to speech in acoustically challenging conditions (Fallon et al. 2002; Elliott et al. 1979). There are indications that the ability to use semantic contextual cues emerges from as young as 19 months (Friedrich & Friederici 2004). However, the contribution of linguistic contextual cues to word recognition in noise is not clear. Fallon et al. (2002) reported that groups of young listeners of 5 and 9 years of age, as well as adults, show comparable gains from linguistic context when listening to speech in noise. On the other hand, Elliott et al. (1979) found that the performance of children of 9 years of age was significantly poorer than that of children of 11 years of age on the highly predictable sentences of the Speech Perception in Noise Test (SPIN) (Kalikow et al. 1977) at a SNR of 0 dB. Further clarification on the developmental changes regarding the ability to benefit from linguistic context is an important issue to resolve since children are often expected to understand and learn from speech presented in relatively noisy classrooms (Picard & Bradley 2001).

There are indications that normal hearing children show individual variability in their ability to benefit from linguistic context when listening to speech in noise. One underlying factor may be the acquisition of linguistic skills, which is not completed until adolescence and show inter individual differences (Bloom & Lahey 1978). Personal factors, such as living in a bilingual family environment, may also affect the acquisition of linguistic skills or vocabulary and induce differences in the ability to benefit from contextual cues for understanding speech in noisy backgrounds (e.g. Mayo et al. 1997). Few studies have explored individual variability in the amount of benefit derived from the linguistic context (e.g., Rönnberg et al. 1998; Grant & Seitz 2000) and, to the knowledge of the authors, none of these studies have explored this variability among children groups.

Because of the expected variability in children performance, group analysis may not always be the best strategy to explore the benefit from linguistic context since averages can be affected by very high and low scores. An alternative is to conduct cluster analysis to determine the presence of specific profiles within a group. Cluster analysis is a statistical tool used to classify data into subgroups, and does not require any prior knowledge of which element will affect the grouping or which groups will be formed (Kacprzyk & Wesam Ashour Wu 2009). In a cluster analysis, every interdependent relationship is considered and no distinction is made between dependent and independent variables.

The objective of the present study is to explore normal hearing children's variability in benefiting from linguistic context when listening to speech in background noise. For this, the *Test de Phrases dans le Bruit* (TPB) (Lagacé et al. 2011) will be used. The TPB is a Canadian French speech-in-noise test that was recently developed following an approach similar to the one used for the development of the original English version of the SPIN test. The TPB includes five recorded lists of forty Canadian French sentences. Like in the SPIN test, in each list, half of the sentences are highly predictable (HP), which means that identification of the key word can be facilitated by contextual information from the sentence (e.g. *The candle flame melted the* *wax*; Kalikow et al. 1977). The other half comprises 20 sentences with low predictability (LP), conveying little contextual information (e.g. *Paul can't discuss the* *wax*; Kalikow et al. 1977). The listener is required to repeat the final word (key word) of each sentence. Performance is measured as the percent correct score on HP and LP sentences separately in each list. The difference in key word recognition between the HP and LP sentences gives information about the listener's ability to benefit from contextual cues. The TPB is intended to be used with both school-aged children and adults. The data presented in this study were gathered during the normative data collection for the TPB.

## METHODS

### Participants

Prior to the commencement of the study, ethics approval was obtained from all the institutions where the research was conducted. A sample of 69 participants (46 females and 23 males) aged between 9 years and 2 months and 12 years and 5 months, all native Canadian French speakers, was recruited from French schools in the Ottawa region (Ontario, Canada). One parent of each participant signed the consent form and completed a questionnaire to rule out the presence of any exclusion criteria.

### Procedure

Each participant was tested individually in a quiet room in the school with ambient noise levels not exceeding specifications for hearing screening in schools (ASHA 1997). A hearing screening at a hearing level of 20 dB HL was performed with a portable audiometer (Madsen Midimate 622) and TDH-39 headphones prior to the experimental phase. All the participants had normal hearing sensitivity at 500, 1,000, 2,000 and 4,000 Hz, bilaterally. Participants were told that they would hear sentences presented first with babble noise and then without noise. They were asked to repeat the last word of each sentence and encouraged to guess if necessary. Sentences from the TPB were used as well as eight-talker (4 males and 4 females) European French babble (Perrin & Grimault 2005). This pre-recorded European French babble was chosen over recordings of English babble because it better approximated the type of masking experienced by the listeners in daily life (no standardized recording of speech babble by Canadian French speakers was available at the time of the study). The TPB sentences and the babble noise were presented diotically via headphones.

Participants first listened to a practice list of 10 sentences presented at a SNR of +4 dB. The experimental phase then consisted of 3 other lists presented at different SNRs. Total experimentation time was approximately 20 minutes. Children were then invited to choose an item (hockey cards, stickers, notepad, pencils, etc.) as a small thank you gift for their participation.

## RESULTS

### Effect of age

A subgroup (n=10) of children (6 females and 4 males) aged from 9 years 8 months to 10 years 11 months (the 9-10 years old group) and another subgroup (n=11) of children (9 females and 2 males) aged from 11 years 2 months to 12 years 5 months (the 11-12 years old group) were administered the TPB to explore the effects of age on performance in interaction with the amount of contextual information and the degree of difficulty. The TPB was administered at three SNRs: -2, 0 and +2 dB. The order of presentation of the SNR was different for each participant.

Performance scores for the two age groups (9-10 and 11-12 years old) are given in Table 1. The average performance for each type of sentence and the difference score were slightly higher for the 11-12 age group than the 9-10 age group. A mixed ANOVA was conducted with the factors *SNR* (3 levels: SNR -2, 0 and +2), *Sentence type* (3 levels: HP, LP, and difference score) and *Age* (2 levels: 9-10 and 11-12 years of age). S*NR* and *Sentence type* were repeated measures variables while *Age* was an inter-subject variable. Results from the ANOVA revealed a significant effect of the main factors *Sentence type* [$F_{(2,38)}$ = 192.63, $p$=0.000, $\eta^2$=0.91)] and *SNR* [$F_{(2,38)}$ = 182.60, $p$=0.000, $\eta^2$=0.91)], but not *Age* [$F_{(1,19)}$ = 1.90, $p$=0.184, $\eta^2$=0.09]. The double interactions *Sentence type* X *Age* [$F_{(2,38)}$ = .20, $p$=0.842, $\eta^2$=0.01] and *SNR* X *Age* [$F_{(2,19)}$ = 0.32, $p$=0.72, $\eta^2$=0.02)] were not significant, but the interaction *Sentence type* X *SNR* was significant [$F_{(4,76)}$ = 13.29, $p$=0.000, $\eta^2$=0.41)]. The triple interaction *Sentence type* X *SNR* X *Age* was not significant [$F_{4,76)}$ = 0.04, $p$=0.998, $\eta^2$=0.00)].

The second level of analysis investigated the degree of conformity of individual patterns with the trends described in the group analysis. For this purpose, the proportion of participants who had score within the total group average ± 1 standard deviation was computed, as shown in Table 1. In general, individual patterns show a certain level of congruence with the total group results, close to the expected proportion of 68 % for a normal distribution of scores. At a SNR of 0 dB, however, the proportion of participants who obtained a correct score within ± 1 standard deviation of the total group average on HP and LP sentences is lower than 60 %, reflecting a greater heterogeneity of the sample. In this case, interpretation of group results may not accurately reflect performance of each individual in the group because of either very low or very high scores.

**Table 1:** Average percentage correct key word recognition for each age group with standard deviation (in parentheses) and difference score at SNRs of -2, 0 and +2 dB, and total group average. For each measure, the proportion of participants with scores within total group average ± 1 standard deviation is indicated.

| | **9-10 years old** | **11-12 years old** | **Total** | **Proportion of score within ± 1 sd from the total group mean** |
|---|---|---|---|---|
| | | SNR = -2 dB | | |
| HP | 33 % (±13) | 40 % (±16) | 37 % (±15) | 13/21 (61 %) |
| LP | 21 % (± 8) | 25 % (±17) | 23 % (±14) | 18/21 (86 %) |
| DS | 12 % (±13) | 16 % (±13) | 14 % (±13) | 13/21 (61 %) |
| | | SNR = 0 dB | | |
| HP | 63 % (±11) | 68 % (±11) | 65 % (±11) | 12/21 (57 %) |
| LP | 40 % (±12) | 41 % (±13) | 40 % (±12) | 11/21 (52 %) |
| DS | 23 % (±12) | 27 % (± 8) | 25 % (±10) | 13/21 (61 %) |
| | | SNR = +2 dB | | |
| HP | 86 % (±10) | 90 % (± 5) | 88 % (± 8) | 15/21(71 %) |
| LP | 56 % (± 8) | 59 % (±15) | 58 % (±12) | 13/21 (61 %) |
| DS | 30 % (± 9) | 32 % (±13) | 31 % (±11) | 13/21 (61 %) |

### Effect of SNR and the linguistic contextual information

Because there was no indication of developmental effects on speech perception in noise between the two age groups (9-10 and 11-12 years), the data were pooled with the 48 remaining participants, for a total sample of 69 children. These 48 additional participants were exposed to three different SNRs (between -6, -4, -2, 0, +2 and +4 dB) to obtain data on a wider range of noise conditions. Results are summarized in Figure 1. A consistent finding is that the mean average of the correct scores for the HP sentences is higher than for the LP sentences at all the SNRs tested, by at least 7 % (at SNR=-3 dB) and up to 28 % (SNR=+2 dB), illustrating the contribution of the linguistic contextual information to auditory speech perception.

Psychometric functions of the group average score (in percentage) for HP and LP sentences as a function of SNR were fitted using a cumulative normal distribution metric with two free parameters (midpoint, slope). The functions illustrated in Figure 2 represent the fitted average score data as a function of SNR for both sentence types as well as the fitted average difference score. The average SNR at which 50 % of the key words were recognized was +0.8 dB for LP sentences and –1 dB for HP sentences. This 1.8 dB difference in SNR to achieve 50 % correct key word recognition in LP and HP sentences represents the contribution of the linguistic contextual information to auditory speech perception for children 9-12 years in age with the TPB.

Another way to look at the contribution of linguistic context in the TPB is by means of the difference score between performance on the HP and LP sentences. The difference in score between the psychometric functions for HP and LP sentences is plotted as a function of SNR in Figure 2. The SNR for which a maximum is reached on this function represents the noise condition where listeners benefit the most from the use of the linguistic contextual cues. In Figure 2, a maximum fitted difference of scores of 20 % is observed at a SNR of 0.8 dB. This group analysis is useful to observe general trends, but it does not necessarily reflect typical performance of individuals in the group. As seen on Figure 1, standard deviations were quite large at some SNRs, probably due to either very low or very high scores.

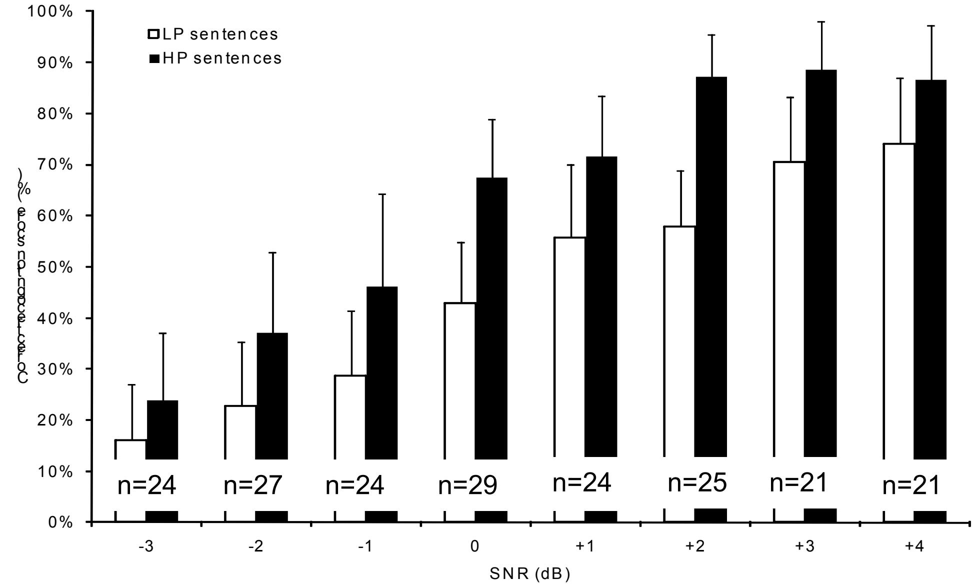


**Figure 1:** Average percentage correct score for LP sentences (white columns) and HP sentences (black columns) at the different SNRs tested, with the sample of 69 children from 9 to 12 years of age.

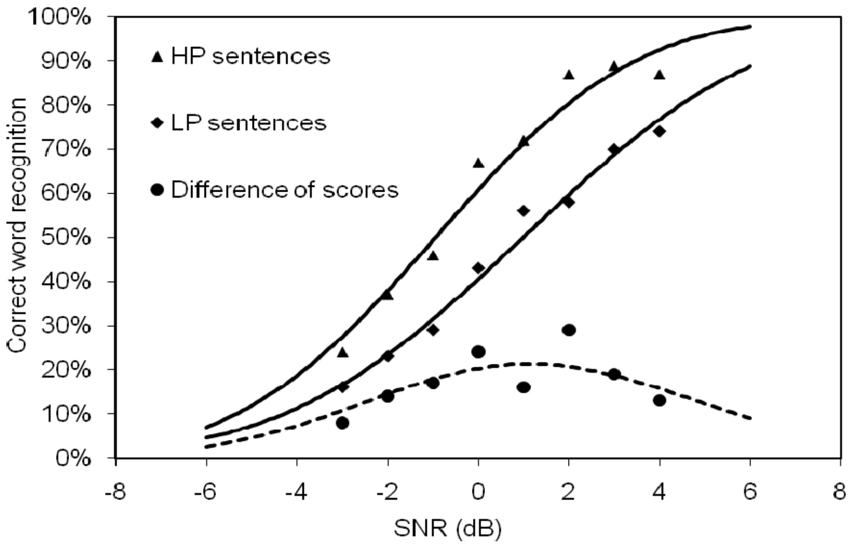


**Figure 2:** Psychometric function of the percentage of key word recognition for HP sentences (triangle symbol), LP sentences (square symbol) and difference score (round symbol) as a function of signal-to-noise ratio (SNR) (N=69).

## Cluster analysis

Cluster analysis on the individual psychometric functions was conducted to capture specific profiles within the children group. To insure uniformity in the computation of the psychometric functions, the analysis was conducted on participants who were exposed to the same number of experimental conditions. As such, the data of 13 participants were removed as they were tested at only two SNR conditions (as opposed to three conditions) because of a lack of time during the experimental phase. Also, to prevent outliers forming clusters with small number of cases, the data from two other participants were taken out prior to the cluster analysis.

The hierarchical cluster analysis was run on the remaining 54 cases using four variables extracted from the psychometric functions for each participant: the value of the SNR threshold to reach 50 % correct score on the LP and HP functions, and the slope of the LP and HP functions. The analysis, conducted using Ward's method, produced two clusters of participants for which some variables were significantly different, as described in Table 2.

The first cluster (n= 25) is characterized by a lower SNR threshold than the second cluster (n= 29) for a 50 % correct score on the LP sentences (-0.6 dB versus 1.9 dB respectively) a difference of 2.5 dB between groups. The first cluster has also a lower SNR threshold for a 50 % correct score on the HP sentences (-1.8 dB) compare to the second cluster (-0.3 dB), a difference of 1.5 dB. The slope of the psychometric functions for the HP and LP sentences were similar.

**Table 2:** Descriptive table of the two clusters that emerged from the data

| | Cluster | N | Mean | Standard deviation | F | Sig.* |
|---|---|---|---|---|---|---|
| Age | 1 | 25 | 133 months | 11 | 2.981 | .090 |
| | 2 | 29 | 128 months | 9 | | |
| | Total | 54 | | | | |
| SNR LP | 1 | 25 | -0.6 dB | 2.00 | 36.84 | .000***** |
| | 2 | 29 | 1.9 dB | 0.91 | | |
| | Total | 54 | | | | |
| SNR HP | 1 | 25 | -1.8 dB | 1.01 | 28.275 | .000***** |
| | 2 | 29 | -0.3 dB | 0.96 | | |
| | Total | 54 | | | | |
| Slope LP | 1 | 25 | .26 dB/SNR | 0.10 | 0.576 | .451 |
| | 2 | 29 | .28 dB/SNR | 0.13 | | |
| | Total | 54 | | | | |
| Slope HP | 1 | 25 | .37 dB/SNR | 0.12 | 0.098 | .756 |
| | 2 | 29 | .38 dB/SNR | 0.11 | | |
| | Total | 54 | | | | |

A one-way ANOVA was conducted to confirm which classifying variables were statistically different between the groups. There was a significant difference between the group means of the SNR for the LP sentences [$F_{(1,53)}$ = 36.839, $p$=0.000)] and the SNR for HP sentences [$F_{(1,53)}$ = 28.275, $p$=0.000)]. The group mean was not significantly different between the two clusters for the variables age and slope value for the LP sentences and for the HP sentences.

A set of statistical analysis was done to explore the benefit of linguistic context between the two clusters. A one-way ANOVA was conducted on the maximum HP-LP difference score and the SNR value at which the maximum difference score was observed for each case in the two clusters. The results for the maximum difference score did not reach significance level [F = 3.484, $p$ = .068] between the first cluster (mean: 25 %) and the second cluster (mean: 30 %), suggesting that both groups showed comparable gains from linguistic context when listening to speech in background noise. However, a significant difference [F = 7.812, *p* = .007] was observed for the value of the SNR at which the maximum difference score was measured between the two groups (first cluster: SNR of 0.4 dB, second cluster: SNR of 1.6 dB), indicating that participants in the second cluster required a more favourable SNR than those in the first cluster to get comparable benefit from linguistic context.

## CONCLUSION

The results of the present study should be interpreted with caution since only children with normal hearing function without developmental condition participated in the experiment. However, there is an indication that a dynamic approach is needed when analysing the performance of children on speech perception in noise tests. Two subgroups of children, not related to age, emerged from the sample. Both groups showed comparable benefits from use of linguistic context when listening to speech in background noise, but the first cluster required a less favourable SNR than Group 2 to achieve comparable performance.

The SPIN-alike tests, such as the TPB, mimics real life listening conditions. Just as there are some situations in children's life where linguistic and contextual information are available and redundant, there are some situations where there is not as much redundancy, for example, when listening to a new topic in the classroom. As reported by Picard & Bradley (2001), many studies have reported noise levels in excess optimal conditions for understanding speech in the classroom, bringing less than ideal levels of SNRs. For example, Blair (1977) reported SNR values in the classroom ranging from -7 to 0 dB and Finitzo-Hieber (1988) reported SNR values ranging from +1 to + 4 dB. Listening at such SNRs would be very challenging for the group of participants of the present study, especially for the children in the second cluster who would not greatly benefit from the linguistic context because of too low SNR. The situation could be even worse for children with learning difficulties who require higher SNR to understand speech when in presence of noisy background (Bradlow et al. 2003) or bilingual children (Bovo & Callegari 2009) who may not benefit as much from linguistic contextual information.

## ACKNOWLEDGMENTS

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# Improvement of speech privacy in open-plan offices

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## ABSTRACT

The present study evaluates subjective aspects of single number quantities stated in the ISO 3382-3 draft, and investigates how design parameters influence speech privacy in computer simulated open-plan offices. Auditory experiments were carried out to rate intelligibility in simulated sound fields with variations of $DL_{2,S}$, $L_{p,A,S,4m}$, and $r_D$. The results of the experiments indicate that the newly-proposed single number quantities are highly correlated with speech intelligibility scores, and the contribution of $DL_{2,S}$ to speech intelligibility score was greater than those of $L_{p,A,S,4m}$ and $r_D$. Computer models of the actual offices were then developed using the commercial room acoustic software, and parametric studies were conducted using computer simulated open-plan offices. The design parameters studied in the present study were screen height, room height, ceiling absorption, floor absorption, screen absorption, light fixture, and workstation size. From the computer simulation, the influence of each design parameter was investigated.

## INTRODUCTION

Open-plan offices have become common in most office buildings to create an environment for both concentration and communication. However, the acoustic quality of open-plan offices has not been satisfactory because irrelevant information from neighboring work places can cause disturbance and distraction (Helenius et al. 2007). Therefore, one of the important goals of acoustical design in open-plan offices has been to provide adequate speech privacy to prevent occupants from being disturbed by sounds from neighboring workstations.

Recently, Virjonen et al. (2009) proposed new single number quantities to characterize the acoustical conditions of the whole office space considering the far field. These new single number quantities are the spatial decay rate of A-weighted SPL of speech, $DL_{2,S}$ [dB], the A-weighted SPL of speech at 4 m, $L_{p,A,S,4m}$ [dB], and distraction distance, $r_D$ [m]. Based on the report by Virjonen et al. (2009), international standardization of the measurement procedure for these single number quantities has been discussed in ISO TC43 SC2 WG19, and the ISO 3382-3 (2010) draft has been published (ISO 3382-3 2010). However, subjective assessment using the newly proposed measures has not yet been performed. Therefore, subjective aspects of the newly proposed single number quantities stated in the ISO draft have to be validated prior to the standardization.

The present study aimed to investigate subjective aspects of the single number quantities discussed in WG19 and to investigate the effects of design parameters of open-plan offices on the single number quantities. A suitable single number quantity was investigated through auditory experiments, providing information regarding the degree of speech privacy. Auditory experiments were carried out in a laboratory with a group of adults in simulated sound fields. During the auditory experiments, the sentence intelligibility score was adopted as a subjective measure, and the relationships between intelligibility score and the newly proposed single number quantities were investigated. Furthermore, computer simulations were performed to find out the way for improvement of speech privacy considering design parameters.

## AUDITORY EXPERIMENT

### Experimental design

Auditory experiments were conducted using sound fields which represented open-plan offices in which a person was speaking. All sound fields were simulated using the impulse responses measured in open-plan offices in Korea with fixed room acoustical parameters such as reverberation time (RT) and early decay time (EDT). The background noise used in the experiments was 30 dBA ventilation noise recorded in the same open-plan offices.

To investigate the effects of single number quantities on the subjective evaluation of speech privacy, speech levels at 4 m from the sound source ($L_{p,A,S,4m}$) were controlled in the range of 43 dB to 57 dB in increments of 7 dB. Then the spatial decay rate of speech levels($DL_{2,S}$) was distributed from 4 s to 12 in intervals of 4 s, while $L_{p,A,S,4m}$ values were fixed at 43 dB, 50 dB, and 57 dB, respectively. Sound pressure levels of speech used in these auditory experiments are plotted in Figure 1 (a) along a source-receiver distance. Changes in speech levels at receiver positions with fixed background noise levels affected the speech-to-noise ratio (SNR). Therefore, STI values were also varied, and those at receiver positions are plotted in Figure 1 (b). At this point, the distraction distance ($r_D$) was distributed in the range of 4.2 m to 16.0 m.

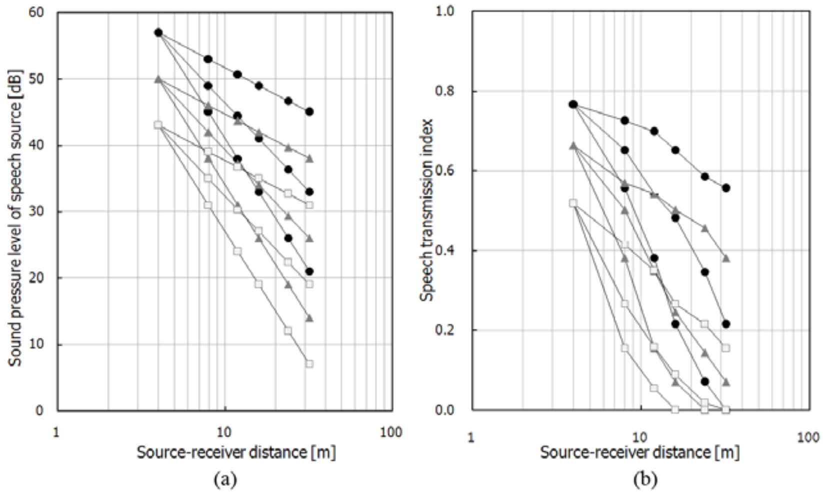


**Figure 1:** Speech levels (a) and STIs (b) along the source-receiver pathway

### Procedure

Twenty subjects participated in the experiment: twelve male and eight female subjects between the ages of 24 and 32. All participants had thresholds ≤ 15 dB HL at octave band frequencies from 0.25 kHz to 8 kHz using an audiometer (Rion AA-77). The speech material used in the experiments was phonetically balanced Korean sentences. During the auditory experiments, five test sentences were presented to each subject in random order for 48 test situations. Thus, each participant listened to a total of 240 test sentences in random order.

All auditory experiments were conducted in a testing booth with approximately 25 dBA of background noise, and test sentences were presented to each subject via headphones (Sennheiser HD 600). Prior to the auditory experiments, each subject completed approximately 10 minutes of training to become familiar with the test signals and background conditions. Intelligibility scores were adopted as subjective measures for the evaluation of speech privacy. Each subject was asked to verbalize the sentences they thought they had heard, and the responses were scored by an experimenter positioned outside the test room. The score for each sentence was determined as the percentage of words that were correctly understood; all words were counted, and no partial scores were given.

## RESULTS

### Effects of $DL_{2,S}$ and $L_{p,A,S,4m}$ on mean speech intelligibility scores

Mean speech intelligibility scores obtained from auditory experiments are presented in Figure 2 in terms of $DL_{2,S}$ and $L_{p,A,S,4m}$. It was found that higher speech levels (that is, smaller $DL_{2,S}$ and larger $L_{p,A,S,4m}$) resulted in higher speech intelligibility scores while $L_{p,A,S,4m}$ and $DL_{2,S}$ were fixed. Figure 2 (a) shows that the changes in mean speech intelligibility score differed according to level of $L_{p,A,S,4m}$ when $DL_{2,S}$ changed from 4 to 8 dB. In this range of $DL_{2,S}$, a lower $L_{p,A,S,4m}$ caused a greater decrease in mean speech intelligibility. However, a similar tendency was observed when $DL_{2,S}$ changed from 8 to 12 dB, although the speech intelligibility scores decreased more rapidly than when $DL_{2,S}$ changed from 4 to 8 dB. This indicates that subjects were sensitive to changes in $DL_{2,S}$ in the range of 8-12 dB.

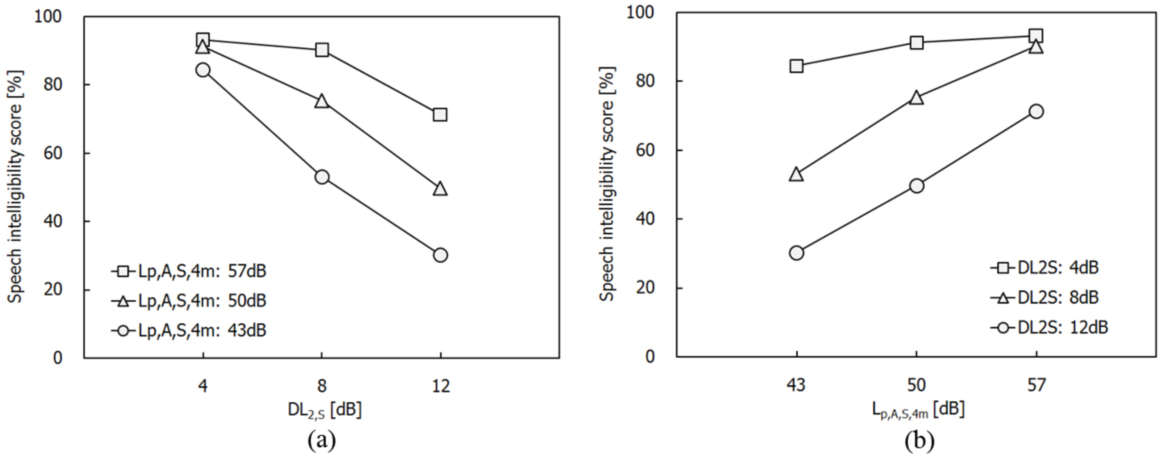


**Figure 2:** Relationships between mean speech intelligibility score and single number quantities ($DL_{2,S}$ and $L_{p,A,S,4m}$)

Figure 2(b) shows a different tendency according to the changes in $L_{p,A,S,4m}$. Mean speech intelligibility scores increased linearly with the increment of $L_{p,A,S,4m}$ when $DL_{2,S}$ values were fixed between 8 and 12 dB, whereas mean intelligibility scores did not change much when $DL_{2,S}$ was 12 dB.

The two-way analysis of variance (ANOVA) for mean speech intelligibility scores was conducted, and the results are listed in Table IV. It was found that $DL_{2,S}$ and $L_{p,A,S,4m}$ were statistically significant ($p<0.01$), although the effects of the interaction between them were not significant. Thus, $DL_{2,S}$ and $L_{p,A,S,4m}$ contributed to the speech intelligibility scores independently, so mean speech intelligibility scores ($SIS_{mean}$) can be expressed as

$$SIS_{mean} \approx f(DL_{2,S}) + f(L_{p,A,S,4m}) \approx a(DL_{2,S}) + b(L_{p,A,S,4m}). \quad (1)$$

The standardized partial regression coefficients of $DL_{2,S}$ and $L_{p,A,S,4m}$ in Eq. (1) were -0.55 and 0.41, respectively, and these coefficients were statistically significant ($p<0.01$ for $a$ and $b$). Using these values, the obtained total coefficient of 0.68 was significant ($p<0.01$). Based on the results of ANVOA, the contributions of $DL_{2,S}$ and $L_{p,A,S,4m}$ to the mean speech intelligibility score were calculated. As presented in Table 1, the contribution of $DL_{2,S}$ to the mean speech intelligibility score was slightly greater than that of $L_{p,A,S,4m}$.

**Table 1:** Results of two-way ANOVA for mean speech intelligibility scores with factors of $DL_{2,S}$ and $L_{p,A,S,4m}$.

| Factor | Degrees of freedom | Sum of square | Mean square | F-test | p value | Contribution (%) |
|---|---|---|---|---|---|---|
| $DL_{2,S}$ | 2 | 6931.705 | 3465.853 | 6.521 | < 0.01 | 51.1 |
| $L_{p,A,S,4m}$ | 2 | 5464.974 | 2732.487 | 5.141 | < 0.02 | 40.3 |
| Residual | 4 | 1161.458 | 387.153 | | | |

Post hoc comparisons via Tukey's test indicated that the differences between $DL_{2,S}$ scores from 8 dB and 12 dB and those from 4 dB and 12 dB were significant ($p<0.05$). However, differences between $DL_{2,S}$ scores from 4 dB and 8 dB were not significant. Similarly, the differences between scores of $L_{p,A,S,4m}$ were statistically significant ($p<0.05$), except for the cases of 43 dB and 50 dB.

## Effect of $r_D$ on mean speech intelligibility score

Mean speech intelligibility scores obtained from auditory experiments can also be explained by another single number quantity, $r_D$. Figures 3(a) and 3(b) show how $r_D$ is related to $DL_{2,S}$ and $L_{p,A,S,4m}$, respectively. As presented in Figure 3(a), only two $r_D$ values were plotted in the case of 4 dB of $DL_{2,S}$ because STI did not decrease to 0.5 when $L_{p,A,S,4m}$ and $DL_{2,S}$ were 57 dB and 4 dB. Mean speech intelligibility scores increased as $r_D$ increased, while the scores showed large variation according to $DL_{2,S}$

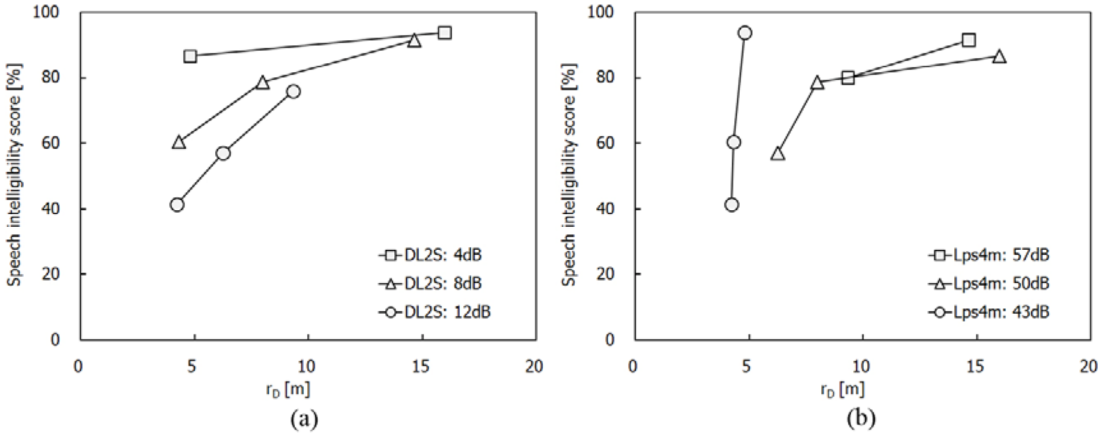


**Figure 3:** Relationships between mean speech intelligibility score and $r_D$

when $r_D$ was less than 5 m. A significant tendency between $L_{p,A,S,4m}$ and $r_D$ is not shown in Figure 3(b), but mean speech intelligibility scores also had large variation when $r_D$ was less than 5 m.

Multiple regression analysis between the mean speech intelligibility score and single number quantities ($DL_{2,S}$ and $r_D$) was conducted to investigate the contribution of each single number quantity to the mean speech intelligibility score. In the regression analysis, $L_{p,A,S,4m}$ was not considered as an input variable because it was highly correlated with $r_D$ ($r$=0.71, $p$<0.05). The relationship between mean speech intelligibility score and two single number quantities ($DL_{2,S}$ and $r_D$) was given by

$$\mathrm{SIS}_{mean} \approx f(DL_{2,S}) + f(r_D) \approx a(DL_{2,S}) + b(r_D). \quad (2)$$

The standardized partial regression coefficients of $DL_{2,S}$ and $r_D$ in Eq. (1) were -0.62 and 0.38, respectively, and these coefficients were statistically significant (p<0.01 for $a$ and p<0.05 for $b$). The regression equation was also significant ($r$=0.56, p<0.05). Contrary to the relationship between $DL_{2,S}$ and $L_{p,A,S,4m}$, the standard regression coefficient of $DL_{2,S}$ was much greater than that of $r_D$. Therefore, the contribution of $DL_{2,S}$ to the mean speech intelligibility score was the highest of the three single number quantities, followed by $L_{p,A,S,4m}$ and $r_D$.

## COMPUTER SIMULATION

### Field measurement

Field measurement was performed in one of the typical open-plan offices in Korea. The plan of the office considered in the present study is illustrated in Figure 4. The office was rectangular shape with similar length and width, and ceiling height was 2.4 m. And screens with heights of 1.2 m were installed between workstations.

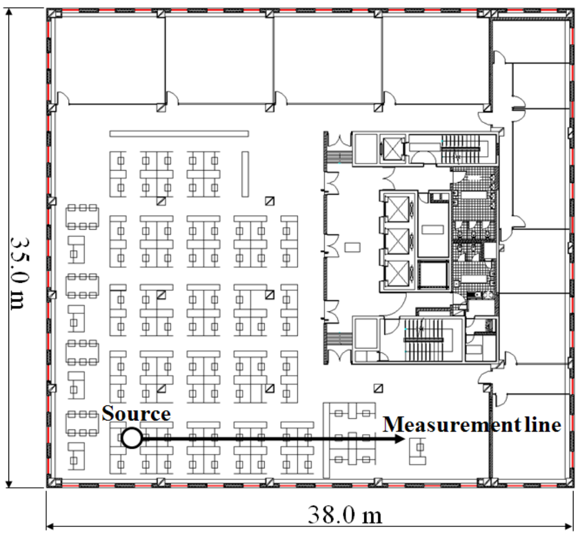


**Figure 4:** Plan of the office and measurement line

Single number quantities obtained from the acoustic measurement are summarized in Table 2. It was observed that T20 and EDT were less than 0.3 s, and the background noise level ($L_{p,A,B}$) was around 34 dBA. In addition, $DL_{2,S}$, $L_{p,A,S,4m}$, and $r_D$ were 5.5 dB, 54.4 dBA, and 10.8 m, respectively. The acoustic class of furnished open-plan offices was proposed in the previous study in terms of $DL_{2,S}$, $L_{p,A,S,4m}$, and $r_D$. The acoustic classes of this office were different according to the single number quantities. This office were classified into the lowest class (D) in terms of $DL_{2,S}$ and $L_{p,A,S,4m}$. But it was also class C in terms of $r_D$.

**Table 2:** Measurement results of single number quantities in open-plan office

| $DL_{2,S}$ [dB] | $L_{p,A,S,4m}$ [dB] | $r_D$ [m] | $L_{p,A,B}$ [dB] | T20 [s] | EDT [s] |
|---|---|---|---|---|---|
| 5.5 | 54.4 | 10.8 | 33.8 | 0.29 | 0.27 |

## Computer modeling

A computer model of the office was created based on acoustic parameters analyzed from the field measurement using the ODEON room acoustic software. Simulations were performed by setting transition order (TO) = 2, by using 33301 rays and truncation time of 600 ms. Moreover, background noise level were set as measured in the office, and absorption and scattering coefficients of interior surfaces were determined considering the real office. For the validation of the computer model, measured and predicted results were compared. Source and receivers for computer simulation were located at same positions of field measurement. It was shown that the results from the simulation showed a good agreement with those from the field measurement within 5 % error.

## Conditions

Previous studies (Bradley 2003; Virjonen et al. 2007) have investigated the effects of various design factors on speech privacy in open-plan offices; ceiling and floor absorption, screen height, workstation plan size, screen transmission loss, light fixtures, and ceiling height. Among those factors, ceiling and floor absorptions, ceiling height, and screen height were considered in the present study as an initial approach. Others will be dealt with in the future study. Ceiling heights were changed from 2.1 to 3.3 m, and absorptions of floor and ceiling were also varied from 0.1 to 0.9 in intervals of 0.2. In addition, screen heights were varied from 0.9 m to 2.4 m.

## Result

Figure 5(a) shows the effect of varying only the ceiling height on acoustical parameters. In general, increasing the ceiling height was not positive to obtain the speech privacy in this office in terms of $DL_{2,S}$, $L_{p,A,S,4m}$, and $r_D$. As ceiling height increased, $DL_{2,S}$ decreased whereas $L_{p,A,S,4m}$ and $r_D$ increased. This is because distances that reflected sounds from the ceiling reached increased as the ceiling height increased.

Figure 5(b) shows the results of predictions when the floor and ceiling absorptions were varied. It was observed that $DL_{2,S}$ increased whereas $L_{p,A,S,4m}$, and $r_D$ decreased when absorptions increased from 0.1 to 0.9. Increasing the ceiling absorption was more effective to enhance the speech privacy than increasing the floor absorption. This result is in accordance with the previous finding (Virjonen et al. 2009) that the ceiling is the most important reflecting surface in open-plan offices, and it is most important that it should be as absorptive as possible.

Figure 5(c) shows predicted values for varied screen heights from 0.9 to 2.4 m high. It was observed that increasing the height of the separating panel significantly affected the speech privacy in open-plan offices. As the height of the screen increased $DL_{2,S}$ increased up to around 10 dB. And the effect of screen height was dominant in the variation of $r_D$.

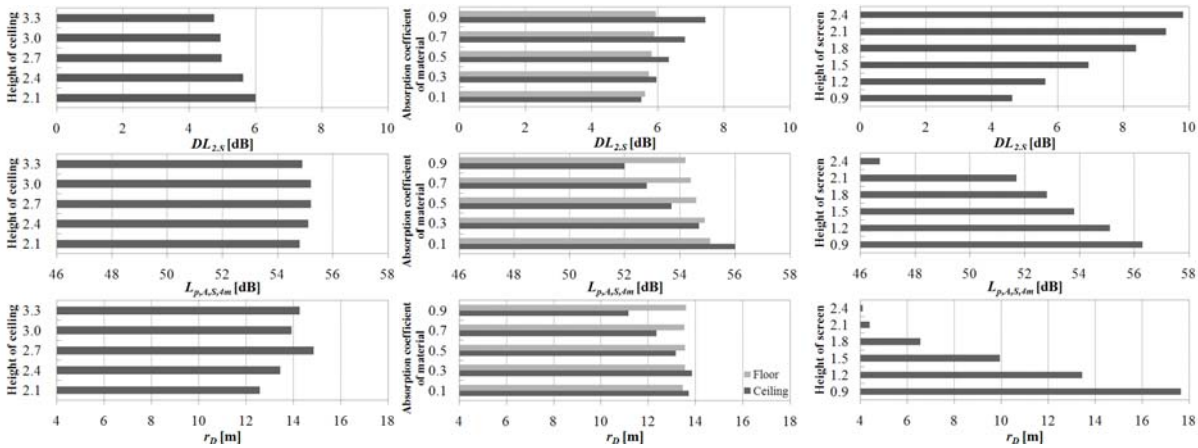

**Figure 5:** Effects of varied ceiling height (a), floor and ceiling absorptions (b), and screen height on speech privacy (c)

## CONCLUSIONS

In the present study, auditory experiments simulated in a open-plan offices were performed to determine the single number quantities of speech intelligibility suitable for speech privacy. $DL_{2,S}$ and $L_{p,A,S,4m}$ were found to be good measures of speech intelligibility for characterization of the acoustic properties of large spaces. It was also found that the contribution of $DL_{2,S}$ to speech intelligibility was slightly greater than those of $L_{p,A,S,4m}$ and $r_D$. It was demonstrated through computer simulation that speech privacy can be improved with increases in ceiling absorption and screen height.

## ACKNOWLEDGMENTS

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# Comparison of different vehicle backup-alarm types with regards to worker safety

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## INTRODUCTION

Audible backup alarms installed on mobile equipment are used to warn or alert nearby workers. Still, accidents and fatalities involving vehicles in reverse are reported every year (Murray et al. 2007; NIOSH 2004; Blouin 2005). Two important factors may affect the effectiveness of backup alarms on workers safety (Laroche 1995). Firstly, the uniformity of the sound field behind the vehicle is not guaranteed, in particular for tonal alarms. Secondly, spatial localization of the alarm can be a problem, particularly for workers wearing hearing protectors. Additionally, the noise generated by such devices will propagate and, quite often, be a source of nuisance for residents living in close proximity. In recent years, a new type of vehicle backup-alarm has been drawing increasingly more interest from many industrial sectors. The new alarm, based on the use of broadband noise instead of the typical tonal ("beep") signal, is deemed to reduce environmental noise annoyance close to industrial settings and construction sites and to be more efficient for spatial localization and uniform noise propagation behind vehicles. While conceptually appealing, few published and peer-reviewed scientific studies have demonstrated the advantages and disadvantages of such an alarm to ensure worker safety, particularly in comparison to existing technologies (Burgess & McCarty 2009; Homer 2008; Withington 2004). This two-part study was intended to compare three types of backup alarms: the standard tonal signal, a multi-tone signal and the broadband noise technology. The first part, performed in the field, focused on objective measurements of the sound propagation behind vehicles for various vehicles and terrain configurations. The second part, performed in a laboratory environment, was centered on the measurement of various psychoacoustic metrics (hearing threshold, loudness, and perceived urgency), as well as the study of spatial localization tasks. The paper presents the methods used for the "field" and "laboratory" parts. Results illustrating some of the findings, both from the field and from the psychoacoustic standpoint, are finally presented.

## METHODS

### Sound field behind vehicles

Three backup alarms were tested in this study: i) a standard tonal alarm from Grote (Grote Industries Inc. 2011); ii) a broadband alarm from Brigade (Brigade Electronics 2011) and; iii) a custom-made multi-tone alarm. The multi-tone was proposed by Laroche (1995) as an improvement over the conventional tonal alarm. It was included in this study for comparison with the two other types of signal. The frequency content of the three alarms is illustrated in Figure 1. The sound pressure levels (SPL), measured at approximately 1 m in front of the alarms, are shown as a function of frequency. The multi-tone alarm consists of three major tones located between 1,000 and 1,300 Hz, contrarily to the standard tonal alarm where the acoustic energy is concentrated around 1,250 Hz. For the broadband alarm, the energy is distributed over a larger frequency span, most of the energy being found in the 700-4,000 Hz range.

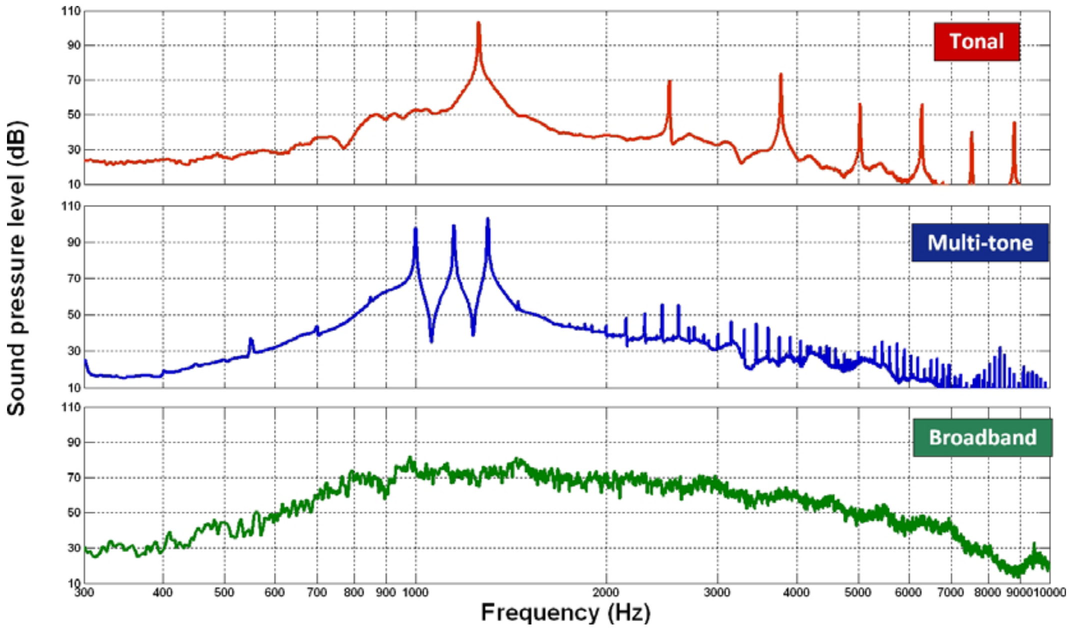


**Figure 1:** Frequency content of the three alarms tested

Tests were performed at three different locations: a sawmill site, a limestone and a quicklime plant. All had different terrain configurations (hard soil or gravel & dirt). To study the sound propagation behind vehicles, a test method inspired from the ISO 9533 standard (1989) was developed. The ISO 9533 procedure was adapted and enhanced to be able to produce, in addition to what is required by the standard, contour maps of the sound field behind the vehicles for the different alarms. BSWA type 1 ½-inch microphones were used in conjunction with an Edirol audio recorder and National Instruments/Labview acquisition system for sound pressure measurements. For the positioning of the alarms on the vehicle, two mounting scenarios were considered: i) a "realistic" one, which consisted of using the alarm as installed on the vehicle (the alarms were off-centered in all three cases tested,) and; ii) an "ideal" one where the alarm was centered, unobstructed and facing outward.

Two sets of measurements were performed for each alarm. In the first set, alarm level adjustments were performed by measuring the sound pressure levels at the seven microphones positions specified in the ISO standard (see Figure 2(a)). The alarm level was then manually adjusted so that a difference equal to or greater than 0 dB (signal-to-noise ratio S/N≥0dB) was obtained at all measurement points between the sound levels generated when the vehicle was operating at high idle without alarm present and those prevailing when the reverse alarm was activated and the truck operated at low idle. For a given vehicle/terrain, the procedure was repeated for each alarm. It allowed examining if one alarm type would require higher levels than the others to maintain the desired S/N≥0 dB at all microphones. A reference microphone was located at a center position 1 meter behind the vehicle to monitor alarm levels.

In a second step, a microphone was mounted to a pole and digital audio recordings were performed while the alarm was activated by moving the microphone slowly along 9 axes and 2 curvilinear arches behind the vehicle (see Figure 2(b)). The alarm levels were set at the values found during the first set of measurements and the vehicle engine was stopped. A post-processing scheme was developed under MATLAB to obtain sound pressure levels along the various lines. Subsequently, an interpolation algorithm was used to produce sound pressure level maps behind the vehicle when the alarm is activated. Such procedure was used to investigate the uniformity of the sound field generated by each alarm.

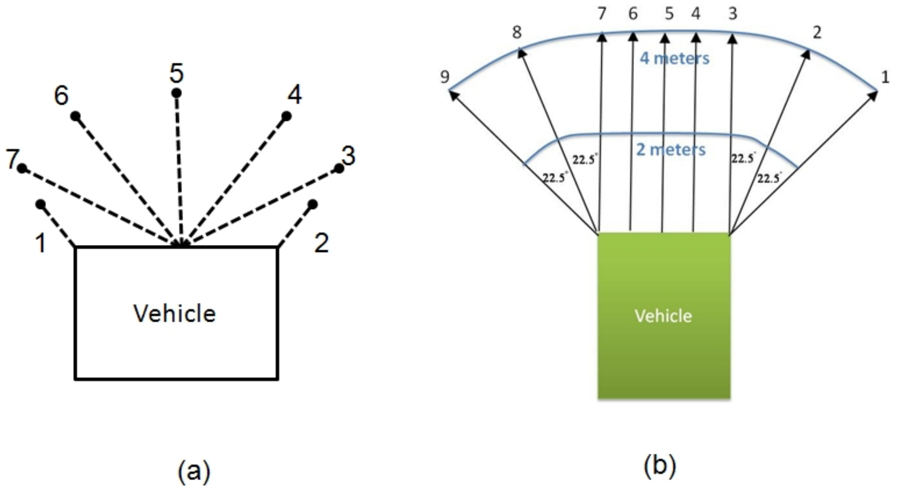


**Figure 2:** (a) Position of the microphones for the alarm level adjustment; (b) Illustration of the scanning lines for sound mapping measurements

### Psychoacoustic measures

Twenty-four subjects with normal hearing (hearing thresholds ≤ 25 dB HL from 250 to 8,000 Hz) took part in laboratory measures of psychoacoustic metrics (detection thresholds, equal loudness judgments and perceived urgency ratings) and spatial localization tasks, both with and without hearing protection devices, in four background noises measured in the field and played back in a noise simulation room. The noises are characterized by various global sound pressure levels (Noise 1 = 81 dBA, Noise 2 = 83 dBA, Noise 3 = 86 dBA, and Noise 4 = 89 dBA) and cover a range of spectra, as illustrated in Figure 3. Half of the sample used Peltor Optime 95 (NRR = 21 dB) earmuff-style hearing protection devices (HPDs), while the rest wore EAR UltraFit earplugs (NRR = 25 dB). In this paper, preliminary results on 16 participants are presented.

Prior to testing, subjects were familiarized with the signals and tasks to be performed. All alarms were played through a single loudspeaker placed 1 meter in front of the subjects, whereas five additional loudspeakers around the subject and one subwoofer were used to create a diffuse noise field.

For threshold measurements, defined as the presentation level at which one can correctly detect 50 % of the presented stimulus, an adaptive method was utilized. Using a tablet PC and a software specifically designed for this study, subjects were required to adjust (using 2-dB steps) the level of each alarm up and down until they were barely audible. Testing was performed twice in each of 5 conditions (quiet + 4 background noises), firstly in open-ear conditions and then with HPDs.

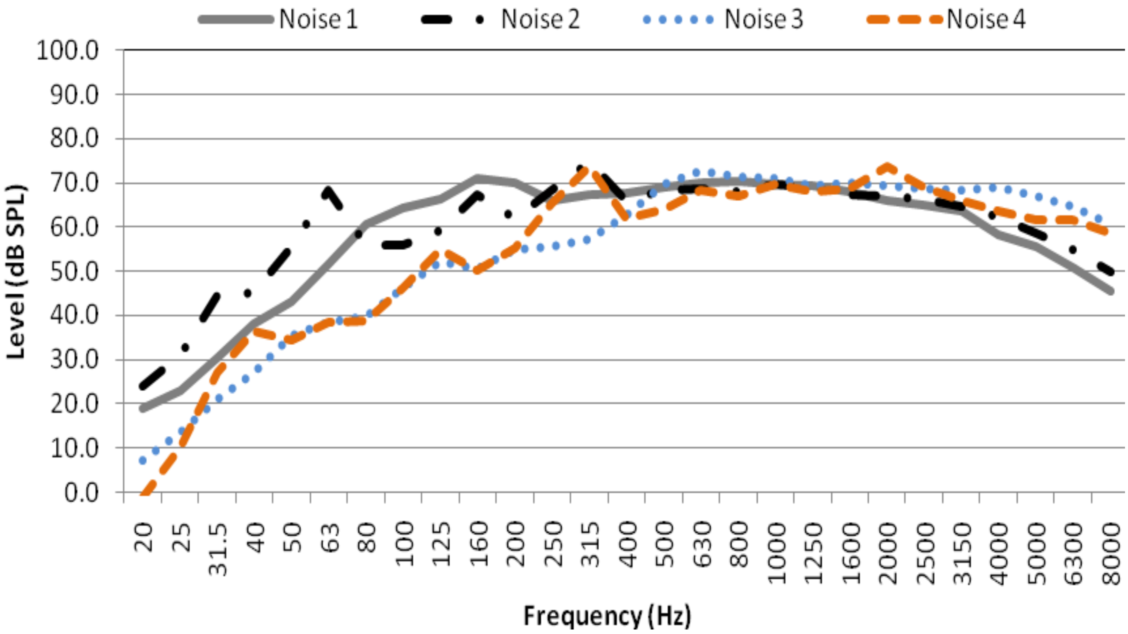


**Figure 3:** Normalized spectra at 80 dBA for the four background noises used in the study

For equal-loudness measurements, the tonal alarm presented at S/N ratio = 0 dB served as the reference alarm. In each of the four noises, participants were required to adjust the sound pressure level of the broadband and multi-tonal signals until they were perceived to be as equally loud as the reference alarm.

Equal loudness does not guarantee that the signals will be perceived by workers as relaying equivalent information about an urgent situation. To investigate the degree of urgency evoked by the different signals, the three backup alarms were randomly presented at three different S/N ratios (-6 dB, 0 dB and +6 dB) while subjects had to rate alarm urgency on a scale of 0 to 100, with a rating of 0 indicating that the alarm was heard but evoked no sense of urgency and 100 being most urgent. Nine urgency ratings (3 alarms x 3 S/N ratios) were performed in each of the 4 background noises, with and without HPD.

Finally, the ability to judge the direction of backup alarm incidence was assessed through a source-identification task in the horizontal plane using a set of 12 loudspeakers arrayed uniformly over a 180° localization arc. Subjects were seated in the center of the localization arc, at a distance of 1 meter from each loudspeaker. Three spatial configurations were tested, with the loudspeaker arc placed at the back of the subjects (to quantify left-right confusions) and to their right and left sides (to quantify front-back confusions). The alarm signals were adjusted to simulate increasing sound pressure levels associated with a vehicle reversing at a speed of 4.4 m/s (10 mph). Testing was performed in one of the selected background noises (Noise 2) at S/N ratios gradually increasing from -6 to 0 dB over 3 seconds, simulating the sound pressure levels at a worker's position as the vehicle is backing up. Following familiarization, a given alarm signal was randomly presented twice from each of the loudspeakers (for a total of 24 trials) and subjects were required to verbally identify the loudspeaker thought to have emitted the sound. Overall, the task consisted of 216 alarm presentations (24 trials X 3 testing conditions X 3 alarms). Testing was repeated with HPDs.

RESULTS

## Alarm level adjustment per ISO 9533

Results obtained for the “S/N≥0 dB” procedure are summarized in Table 1. For each alarm and each site, the mean and standard deviation of the S/N ratio is presented as well as the sound pressure levels at the reference microphone. It is observed that higher levels had to be used for the tonal alarm compared to the multi-tone and broadband ones. Also, higher mean S/N and standard deviations are obtained for the tonal alarm, suggesting more sound level variations for this design.

**Table 1:** Mean (standard deviation) values of the signal-to-noise ratio (expressed in dB) over the 7 microphone locations & sound pressure levels (in dB(A)) at the 1m reference microphone (alarm position: “ideal“ mounting).

| | Site 1 | | Site 2 | | Site 3 | |
|---|---|---|---|---|---|---|
| | Mean (std) | Level @ 1m | Mean (std) | Level @ 1m | Mean (std) | Level @ 1m |
| **Tonal** | 6.9 (4,2) | 107.2 | 8.0 (5.9) | 112.0 | 3.2 (2.3) | 106.0 |
| **Multi-tone** | 3.9 (2,3) | 99.4 | 5.4 (4.0) | 105.2 | 4.9 (3.1) | 102.8 |
| **Broadband** | 1.9 (1.2) | 99.3 | 3.1 (2.9) | 104.9 | 1.0 (0.7) | 102.1 |

## Sound pressure level maps

Maps of the sound pressure levels behind the vehicle are presented in Figure 4 for one of the site (alarms positioned in the “ideal” mounting scenario). Variation of the alarm level on the order of 10 dB within a short range of ~1 meter can be observed for the tonal alarm due to the effect of acoustic interferences. Not surprisingly, this interference effect is quite pronounced when only one strong tonal component dominates. However, it tends to be smoothed out considerably when adding two additional tonal components to the signal, as is the case for the multi-tone alarm. Finally, a relatively uniform sound field was obtained for broadband alarm.

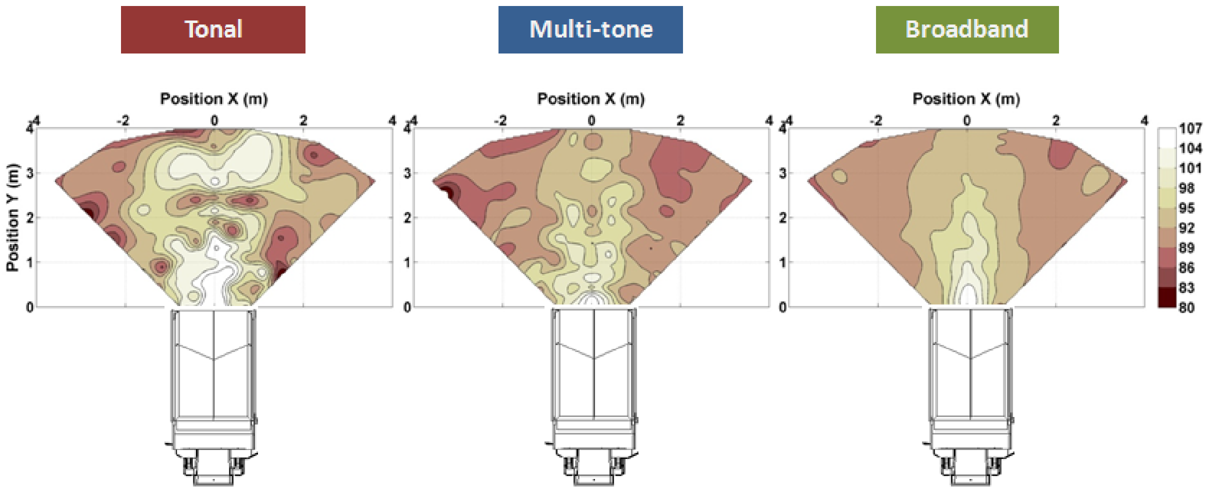


**Figure 4:** Sound pressure levels behind the vehicle (expressed in dB(A)) for one of the site and for the alarms in the “ideal“ mounting position

### Results on psychoacoustic measures and localization data

Preliminary data obtained on 16 of the 24 subjects are presented here for measures of detection, perceived urgency and sound localization. Due to space constraints, only results from the two commercial alarms (tonal, broadband) are presented.

Detection results are expressed as the mean S/N ratio at threshold in Figure 5. As can be seen, the average S/N ratio at threshold is relatively constant across the four noises for the tonal alarm, whereas it seems to depend on the type of noise when a broadband signal is used, being somewhat similar in Noises 1 and 2 and higher in Noises 3 and 4. With greater energy in the high-frequency region, Noises 3 and 4 appear to have a larger masking effect on the broadband signal (which extends into the high frequencies) than on the tonal alarm (whose energy is centered around 1250 Hz) as shown in Figures 1 and 3. In this frequency range, all noise spectra are relatively identical, potentially yielding similar masking effects on the tonal signal, which could explain uniform thresholds for this signal across the noises.

With HPDs, similar trends are observed but thresholds are improved by about 0-2 dB for the broadband signal and 3-4 dB for the tonal alarm. Lower S/N ratios for detection could be attributed to narrower auditory filters and associated decrease in masking effect when testing is performed at lower background noise levels under HPDs, relative to unprotected conditions. Average thresholds in Noise 1 are very similar for both alarms when unprotected, while a difference of 4 dB favoring the tonal alarm is found with HPDs. In Noise 2, protected and unprotected thresholds are very similar for both alarms. In Noises 3 and 4, threshold differences of 4 dB and 6-7 dB favoring the tonal alarm are noted in the unprotected and protected conditions, respectively.

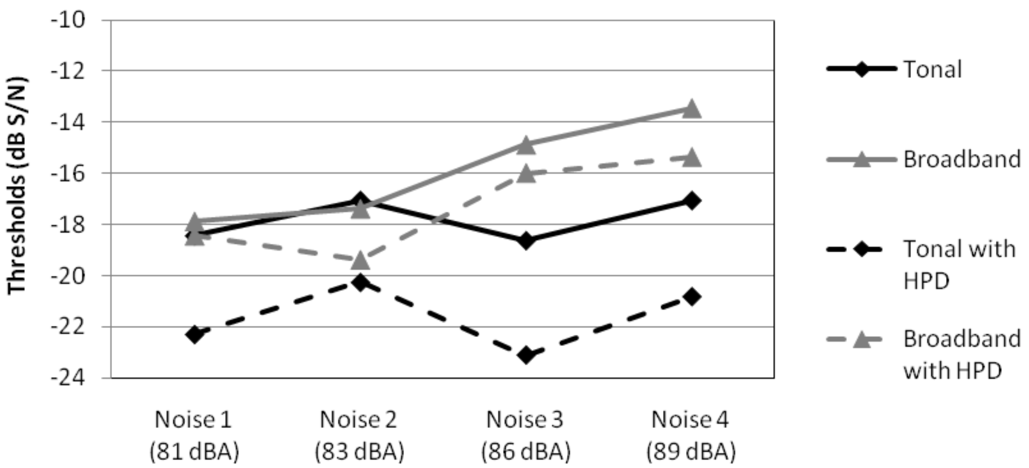


**Figure 5.** Average detection thresholds for the tonal and broadband alarms obtained in four background noises with 16 individuals with normal hearing

Average ratings of perceived urgency for the tonal and broadband alarms are reported for two noises (Noises 1 and 3) at three S/N ratios (-6 dB, 0 dB and +6 dB) in Figure 6. As expected, the degree of urgency conveyed increases with the S/N ratio in a constant noise. Results also vary according to the noise, alarm and listening condition. At the highest S/N ratio (+6 dB S/N) in unprotected conditions, the broadband alarm was rated either equally urgent or more urgent than the tonal alarm, with a 10-point maximum difference in ratings on a 100-point scale. A different trend is noted with HPDs, where the broadband signal is being rated equally or less urgent than the tonal alarm (10-point maximum difference). At this S/N ratio, urgency ratings drop for both alarms when HPDs are worn relative to unprotected conditions, with larger drops noted for the broadband signal (15-30 points) than the tonal alarm (5-12 points).

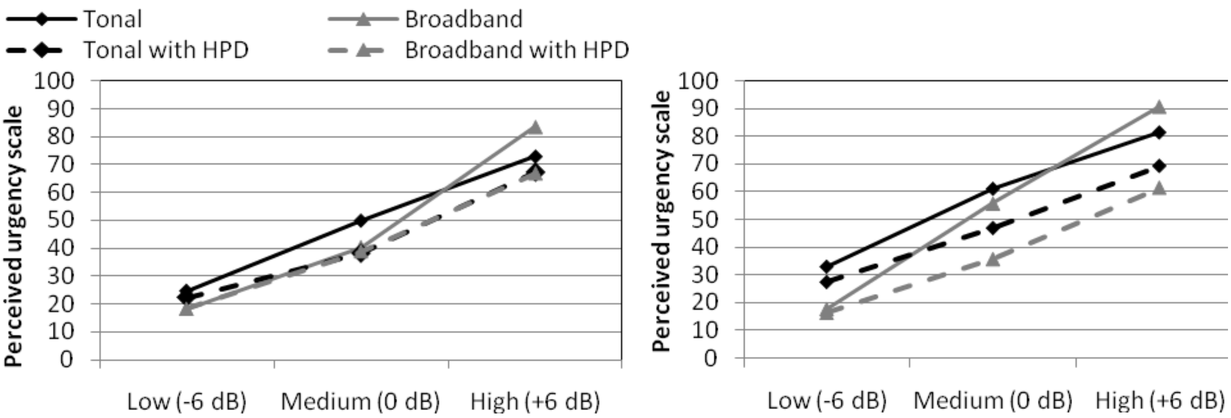


**Figure 6:** Average perceived urgency ratings at various S/N presentation levels obtained with 16 individuals with normal hearing (left panel = Noise 1; right panel = Noise 3)

The average number of left/right and front/back sound localization errors is shown in Figure 7 for tonal and broadband alarms, with and without HPD. A left/right or front/back error occurs when a loudspeaker position within a 90° quadrant is confused with a position in the other 90° quadrant. As expected, the number of errors is greater for the side conditions (front/back judgement) of the localization arc, where localization cues rely heavily on spectral information, than for the condition at the back (left/right judgement), where binaural cues such as interaural time and level differences are used to localize sound. This is noted for both the unprotected condition and when HPDs are used. The number of right/left and front/back errors also increases for both alarms when HPDs are worn, particularly when localization relies on spectral information (front/back dimension).

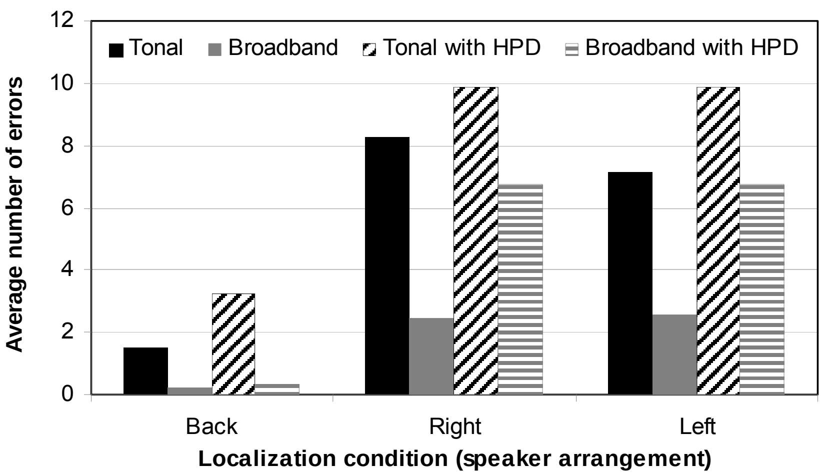


**Figure 7:** Average number of localization errors obtained with 16 individuals with normal hearing in Noise 2. In the back and side conditions, errors consist of Left/Right and Front/Back confusions, respectively

Preliminary results indicate that HPDs can hinder sound localization for both alarms, especially for the front/back judgements in the side conditions. Unprotected, subjects seem to perform better with the broadband alarm. Such effect of the alarm type is particularly evident in the side conditions. The broadband alarm also appears to be easier to localize than the tonal alarm under protected listening conditions. Further data collection and analyses will reveal whether these obervations reach statistical significance.

## CONCLUSIONS

A sampling of acoustic measurements and psychoacoustic data on three backup alarms is presented in this paper. Alarms with a broad frequency content appear to present some advantages over conventional single-tone alarms, including: 1) a more uniform sound propagation pattern behind heavy vehicles; 2) lower sound pressure levels to meet the requirements set forth in ISO 9533; 3) higher urgency ratings at high S/N ratios without protection devices and; 4) better sound localization performance. However, some disadvantages were also noted. Firstly, higher S/N ratios are required for detection of the broadband alarm, at least in noises rich in high-frequency content. Secondly, detection thresholds and urgency ratings appear to be more severely affected by the use of HPDs for the broadband alarm than the tonal alarm.

The preliminary findings and general trends above must be interpreted with caution. Additional data on a greater number of subjects and more comprehensive analyses are required to draw firm conclusions from such findings. Results need to be more thoroughly analyzed form a work safety standpoint, taking into consideration other factors such as environmental annoyance, habituation and familiarity of the alarms.

## ACKNOWLEDGMENTS

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# Intelligibility of speech corrupted by nonlinear distortion

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## INTRODUCTION

Attempts to predict the intelligibility of speech transmitted by a communication system have led to numerous models (see, for example, ANSI 1997; IEC 2003; Christiansen et al. 2010; Elhilali et al. 2003; Kates & Arehart 2005; Payton & Braida 1999; Steeneken & Houtgast 2002a; Yu et al. 2010). Of these, the speech intelligibility index (SII) (ANSI 1997) and the speech transmission index (STI) (IEC 2003) have received most attention. Both provide an index of intelligibility from 0 to 1 based on the speech signal-to-noise ratio in discrete frequency bands. The frequency bands of the SII were originally chosen to reflect the psychoacoustic masking of test sounds by noise (critical bands). The method was later standardized with the speech spectrum alternatively broken down into fewer, broader frequency bands for convenience of calculation (one-third octave, and octave bands from 125 Hz to 8 kHz). The test signals are those naturally occurring in the communication system (i.e., speech and noise, the levels of which need to be separately determined). The STI focuses on the temporal modulation of speech sounds and adopted octave bands as the basis for calculating the modulation spectrum (Steeneken & Houtgast 2002b). It replaced speech by a probe signal to ensure that the modulation could be determined in each modulation frequency band, which have frequencies from 0.63 to 12.5 Hz in the international standard.

In modern communication systems the speech signal is often corrupted by the signal processing and electronic circuitry, as well as by noise, which in some circumstances introduces audible distortion and may degrade intelligibility. The SII and STI have been shown to predict speech intelligibility for a range of conditions in which speech understanding is impeded by continuous noise, but fail when the speech signal is corrupted by nonlinear distortion such as center clipping. In these circumstances the performance of the SII has been improved by calculating the speech signal-to-'noise' (or distortion) ratio from the coherence, which needs to be determined for different amplitude ranges of the speech signal in order to assess the intelligibility (Kates & Arehart 2005). We have explored replacing the test signal of the STI by speech and adjusting the metric for the coherence between the original and corrupted speech, as a means for determining when the observed modulations are due to speech rather than 'noise' (Payton & Braida 1999; Goldsworthy & Greenberg 2004). Also, the contributions to intelligibility from speech information in nearby frequency bands is known not to be independent, and so cannot be simply summed as in some models (e.g., ANSI 1997), resulting in the need to estimate inter-band redundancy (Steeneken & Houtgast 1999; Brammer et al. 2010).

In this paper we briefly describe our models and their application to speech-spectrum shaped noise and center clipping. The latter occurs when a signal within a communication channel rapidly changes polarity from a non-zero value. An example is given in Figure 1, where the time history of a short segment (0.1 s) of a speech sound is shown (above) as well as a corrupted waveform in which 75 % of the amplitude distribution of the speech sounds has been removed (below).

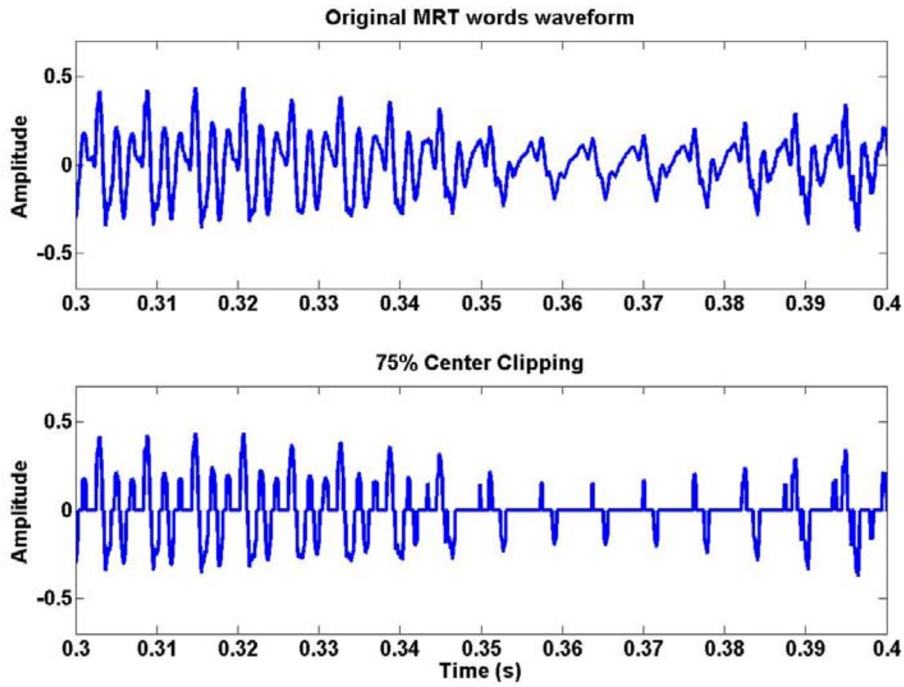


**Figure 1:** Example of center clipping for a 0.1 s time segment of a speech waveform

METHODS

**Speech Transmission Index**

The models employ running speech as the input to the communication system, contrary to the conventional STI method specified in IEC 2003, and are described in detail elsewhere. Other essential components of the traditional STI model are, however, retained, viz. establish changes in the temporal modulation of speech sounds within octave bands with center frequencies from 125 Hz to 8 kHz. Specifically, the ratio of the input to output modulations is first determined in one-third octave bands (with center frequencies, $f$, from 0.63 to 12.5 Hz) from the intensity envelopes of the signals in each octave band ($k$). The magnitude squared coherence between the input and output modulation envelopes is then computed for each modulation frequency band, $\gamma_{k,f}$. The coherence is used to correct the measured modulation reduction, $mi_{k,f}$, to account for situations in which the measured modulation reduction is influenced by the competing noise or distortion (i.e., when the coherence will be reduced):

$$mc_{k,f} = mi_{k,f} * \gamma_{k,f}^2 \tag{1}$$

The corrected modulation reduction, $mc_{k,f}$, is converted to a signal-to-noise (or distortion) ratio, which in turn is adjusted to range from 0 to 1 so that a transfer index can be computed for each modulation frequency band (within each octave band). A modulation transfer index, $MTI_k$, is then computed for each octave band from the arithmetic mean of the transfer indices for that octave band, and used to construct a speech-based STI, according to:

$$STI_{speech} = \sum_{k=1}^{7} \alpha_k MTI_k - \sum_{k=1}^{6} \beta_k \sqrt{MTI_k * MTI_{k+1}} \qquad (2)$$

In this equation, $\alpha_k$ are numerical coefficients that represent the contribution to speech intelligibility from sounds in each octave band. They are equivalent to the 'importance functions' employed in calculations of the SII and are empirically determined from speech tests with human subjects. The second term was introduced with empirical coefficients ($\beta_k$) to account for inter-band contributions to intelligibility arising from speech information common to adjacent octave bands (Steeneken & Houtgast 1999).

The information common to the speech signal in different octave bands may be formally identified by calculating the normalized cross-covariance between intensity modulations in different octave bands, $\rho_{k,j}$ ($j$=$k$+1, …7). For the results reported in this paper we have included interactions between three adjacent octave bands based on observations of real speech (i.e., $j$=$k$+1, $k$+2), and computed the mean cross covariance. The model for predicting intelligibility then becomes:

$$STI_{\rho-speech} = \sum_{k=1}^{7} \alpha_k MTI_k - \frac{1}{6} \sum_{k=1}^{6} \sum_{j=k+1}^{k+2} \left[ \rho_{k,j}^2 * MTI_k * MTI_j \right]^{1/2} \qquad (3)$$

STI values were computed from sound pressures levels (SPLs) recorded at the center-head position in the absence of the subject.

### Modified rhyme test

The modified rhyme test (MRT) was used to characterize the intelligibility of individual words in a six-alternative forced choice paradigm (ANSI 1989). The word lists were those standardized for American English and were a commercial recording by a male talker. Speech sounds were reproduced in an anechoic chamber by a small, high fidelity, low distortion loudspeaker positioned 2.4 m in front of the subject with tweeter at ear height (Paradigm Signature S1 v2) (see Figure 2).

Speech-spectrum shaped noise was produced by four loudspeaker towers surrounding the subject at a distance of almost 2.0 m (each tower consisting of a JVC SRX715F woofer and tweeter, and SRX718 sub-woofer). The signals driving the loudspeaker towers were processed to yield a pseudo-diffuse sound field in the horizontal plane at the center-head position (Yamaha SPX2000 and SP2060). The sound levels were equalized to produce a flat frequency response from 80 Hz to 10 kHz (± 3 dB).

Center-clipped speech was obtained by removing the central 10% to 98% of the long-term histogram of the speech waveform, which consisted of the concatenated MRT words and carrier phrases with the silence between test phrases removed. The distorted signals were adjusted to the same SPL as the unperturbed speech, and replayed to the subject at 65 dBA as measured at the center-head position (in the absence of the subject). The speech-spectrum shaped noise was also reproduced at 65 dBA, and the SPL of the MRT word and carrier phrase were adjusted to the desired speech signal-to-noise ratio (from -17 to +10 dB).

Subjects sat with a computer-controlled touch screen at a convenient height in front of them (see Figure 2) and initiated each test sentence by pressing the 'play' button, whereupon one of six words displayed on the screen was randomly presented within the carrier phrase. Subjects were instructed to choose one of the six words by touching the screen, and then initiate the next trial when they were ready. There were 50 trials in each measurement block from which a word score was derived for a given speech signal-to-noise or distortion. Each measurement was repeated on three separate occasions. Word scores from the three replications were first averaged for each subject before the mean scores were combined across subjects.

**Figure 2:** Determination of word intelligibility

### Subjects

Six healthy subjects ranging in age from 25 to 45 years with normal hearing (3 male and 3 female) participated in all the experiments. Hearing thresholds were determined at study induction and were better than 20 dB HL at audiometric frequencies from 500 Hz to 8 kHz: in addition, the differences in HLs between ears were less than 10 dB. All were native speakers of American English and were paid for their time.

All subjects gave their informed consent to participate in the study, which was conducted according to the provisions of the university's ethics review board.

## RESULTS AND DISCUSSION

Results are presented in Figure 3 for the two STI models described in this paper ($STI_{speech}$ and $STI_{\rho\text{-}speech}$), and for the most recent version of the conventional STI incorporated in the IEC standard (IEC 2003), the so-called $STI_r$ (shown by the line for speech-shaped noise).

The first model, $STI_{speech}$, employs a speech probe signal in which the change in the intensity modulation from input to output has been corrected for the magnitude squared coherence between the original and corrupted speech signals, according to equation 1. The coefficients for the contributions to intelligibility from each octave frequency band ($\alpha_k$) as well as the redundancy corrections ($\beta_k$) are those contained in the IEC standard (IEC 2003), and the metric has been constructed according to equation 2. MRT scores and STI values for this model are shown by the open symbols in Figure 3.

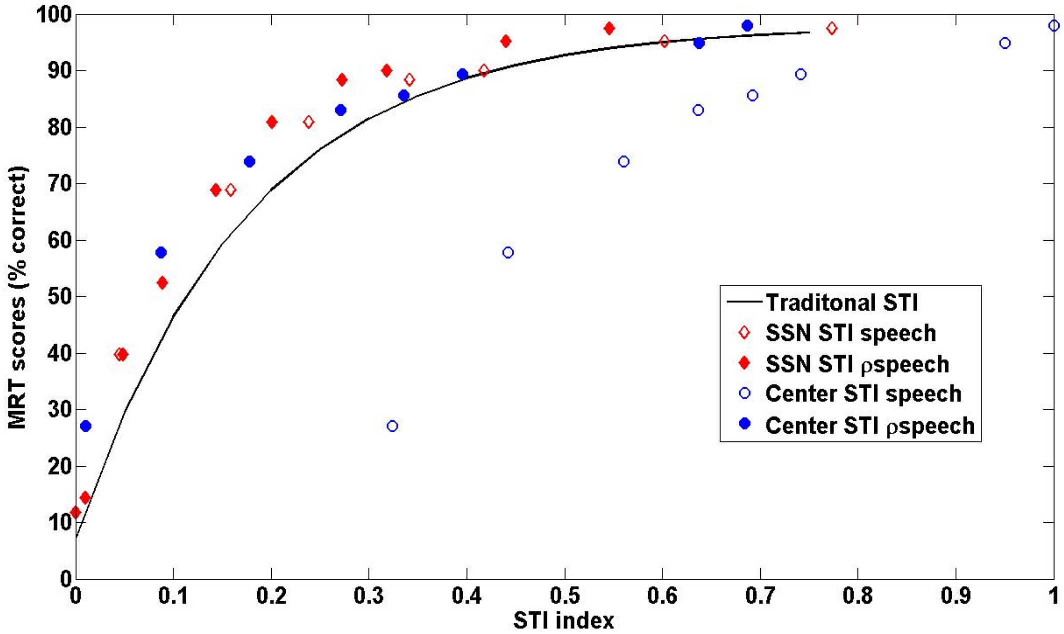


**Figure 3:** Mean MRT scores and predictions using three models for the STI: open symbols - $STI_{speech}$, filled symbols - $STI_{\rho\text{-}speech}$, and line - $STI_r$; 'SSN' - speech-spectrum shaped noise, and 'Center' - center clipping

The second model, $STI_{\rho\text{-}speech}$, also employs a speech probe signal in which the change in the intensity modulation from input to output has been corrected for the magnitude squared coherence between the original and corrupted speech signals. However, in addition, the empirically determined redundancy factors of the IEC standard (IEC 2003) have been replaced by the measured normalized cross covariance of the intensity modulations between adjacent and next nearest neighbor octave bands, according to equation 3. The coefficients for the contributions to intelligibility from each octave frequency band ($\alpha_k$) are again those contained in the IEC standard (IEC 2003). MRT scores and STI values for this model are shown by the filled symbols in Figure 3.

Reference to Figure 3 shows that both models produce similar results and a similar relationship between model values and MRT word scores for speech masked by speech-spectrum shaped noise (the diamonds). The relationship between MRT scores and the two STI indices differ somewhat from the traditional $STI_r$, shown by the line, with $STI_{speech}$ and $STI_{\rho\text{-}speech}$ predicting higher word scores for a given value of the index. Equally important, for a given word score, equations 2 and 3 produce values for the indices that are less than that produced by the traditional $STI_r$, suggesting that the balance between the two terms in equations 2 and 3 may need adjusting.

For speech corrupted by center clipping, it is evident from Figure 3 that only the model incorporating a measure of the correlation between sounds in adjacent and next nearest neighbor octave bands can produce values of the metric that are essentially the same as those for speech-spectrum shape noise. This may be seen by comparing the filled symbols. In contrast, the values of the metric produced by the other model ($STI_{speech}$), shown by open circles, deviate substantially from the values for speech-spectrum shaped noise. A prediction of intelligibility for nonlinear distortion cannot be obtained by the traditional STI method.

It should be noted that the model for speech corrupted by nonlinear distortion developed here contains only seven adjustable parameters, the $\alpha_k$, which have been assigned the values in the IEC standard (IEC 2003). Thus no attempt has been made to optimize the fit of the model to the word scores. An equivalent model for the SII would require 22 fitted parameters to characterize speech corrupted by center clipping (Kates & Arehart 2005).

## CONCLUSIONS

It thus appears that a STI model accounting for the redundancy between speech information contained in nearby octave bands is required to predict the intelligibility of speech corrupted by center clipping. The model proposed here, $STI_{\rho\text{-}speech}$, which includes the mean of the measured contributions to the normalized cross covariance from nearest neighbor and next nearest neighbor bands according to equation 3, can account for center clipping from 10 to 98 % of the speech amplitude-time histogram.

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# Poor acoustical environment: an architectural barrier to people with hearing loss

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Architects and designers typically are not aware that the ability to understand speech develops over time in children, and schools may be built that meet the needs of normal hearing adults but are inadequate for children and individuals with hearing loss. In the United States and elsewhere, school buildings are used for regular school instruction during the day and for adult learning activities in the evenings. Thus, these facilities may be used by individuals with hearing loss where the acoustic environment poses challenges to speech perception and learning (see Figure 1).

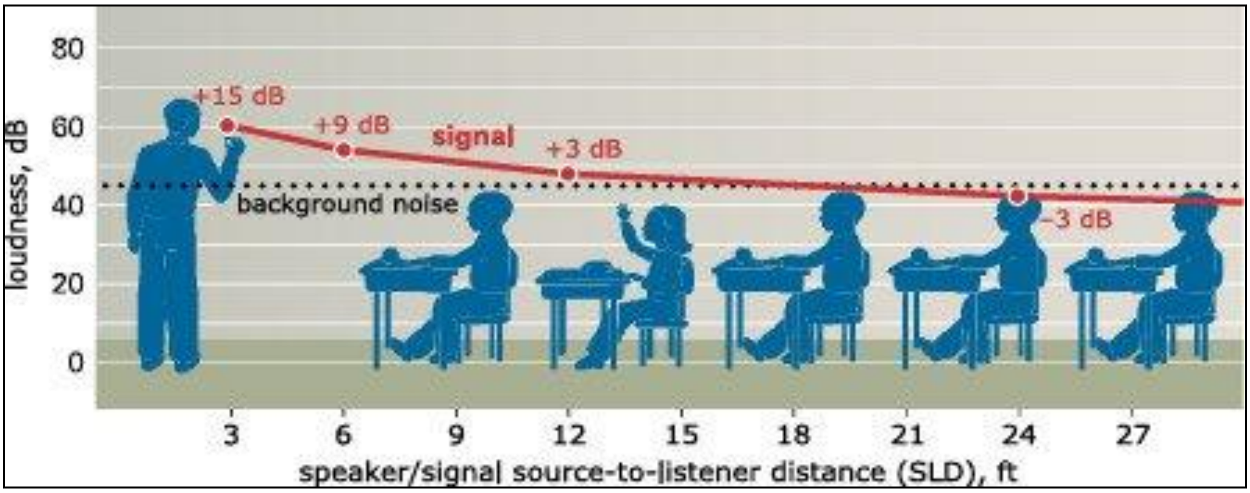


**Figure 1:** Speaker to listener signal-to-noise ratio

Noise in learning environments such as classrooms is unwanted sound usually caused by heating, ventilating, and air-conditioning equipment (HVAC), noise from outside the building leaking through windows and doors, and noise from adjacent rooms and hallways coming through walls and doors (see Figure 2). Reverberation is the persistence of sound after its source quiets and arises from sound reflecting from hard walls, floors, and ceilings (see Figure 3).

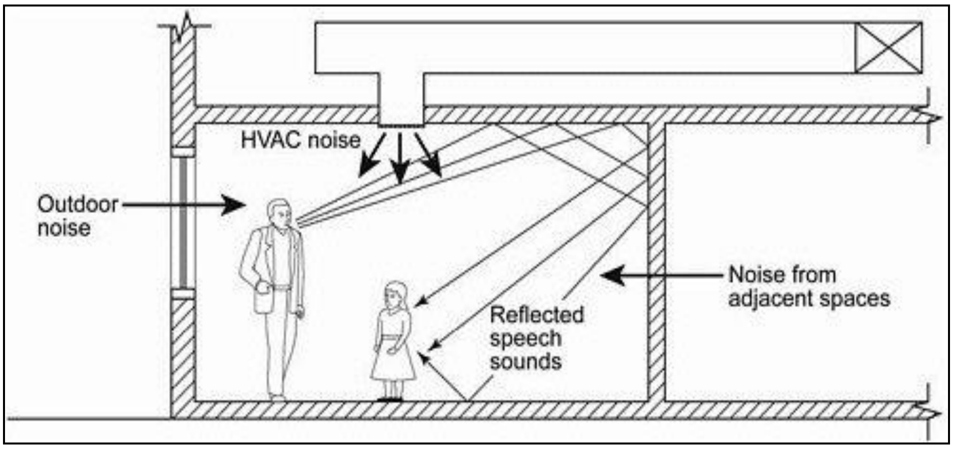


**Figure 2:** Classroom Noise Sources

**Figure 3:** Classroom Reverberation

The American Speech-Language-Hearing Association (ASHA) has been actively involved for more than 15 years in the development of standards for school acoustics and in advocacy efforts designed to bring this issue to the attention of consumers and policy-makers.

Table 1 demonstrates the extensive engagement of ASHA with other organizations, governmental agencies and private organizations over the course of almost 20 years in an effort to achieve a policy adopted in the U.S. that assures an appropriate acoustic environment in classrooms throughout the country.

**Table 1:** Classroom Acoustics Standard Timeline

| | |
|---|---|
| **1994** | Consortium of organizations, including ASHA, submits comments to U.S. Access Board on proposed Rulemaking for State and Local Government Facilities. Comments stressed that a poor acoustical environment is an architectural barrier to people with hearing and visual impairments. |
| **1995** | ASHA published "Guidelines and Position Statement for Acoustics in Educational Settings," which calls for background noise levels not to exceed 30 dB, reverberation times of 0.4 seconds or shorter, and an overall teacher speech-to-competition ratio of + 15 dB. |
| **1996** | Same consortium, with the addition of the Acoustical Society of America (ASA) and Educational Audiology Association (EAA), again submits comments to the U.S. Access Board on amendments to its ADA Accessibility Guidelines (ADAAG) and the Department of Justice's Standards (ADA standards) for Accessible Design to provide specifications for building elements designed for use by children. |
| **1997** | A parent of a child with hearing impairment writes a Petition for Rulemaking to the U.S. Access Board, expressing the same concern as the 1994 consortium of organizations and professionals.<br><br>ANSI Accredited Standards Committee (ASC) S12 (Noise) establishes a new working group to draft classroom acoustics standards. |
| **1998** | A Request for Information (RFI) is published in the *Federal Register* (June 1) by the U.S. Access Board requesting information on acoustics in classrooms. |
| **1999** | Access Board publishes a Notice of Proposed Rulemaking to revise and update guidelines for new construction and alterations covered by the ADA and the Architectural Barriers Act (ABA) to harmonize with the International Code Council's International Building Code/American National Standards Institute (ANSI) A117.1 |
| **2001** | ASC S12 votes on a draft of S12.60, which receives two negative votes, one of which was reversed. The second negative (by Air-Conditioning, Heating and Refrigeration Institute) is sustained and is the subject of appeals continuing through 2002-2003.<br><br>The Access Board applies to the ICC to amend the International Building Code (2003 edition) to include portions of or reference to the standard (still in draft). |
| **2002** | Access Board publishes request in the *Federal Register* for public review of draft guidelines revising the ADA and ABA Accessibility Guidelines. ANSI approves ANSI S12.60-2002 *American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools* (June). |
| **2006** | In response to a Modular Building Institute (MBI) proposal, ASC S12 creates a new working group, Acoustical Performance Criteria for Relocatable Classrooms. |
| **2007** | ASC S12 votes on reaffirmation of ANSI S12.60-2002 with no proposed changes. Various parties raise objections. A plan is established to revise ANSI S12.60-2002 after the completion of the work regarding relocatable classrooms and other related projects. |
| **2008** | S12 approves a new working group, Revision of S12.60, which will not begin work until the relocatable project is substantially complete. |
| **2009** | ANSI approves the reaffirmation and re-designation of the standard, now designated ANSI/ASA S12.60-2002 (R 2009). Work begins (September) on the revision of ANSI/ASA S12.60-2002 (R 2009).<br><br>The Access Board applies to the ICC (September) to amend the International Building Code to include references to the new editions of the classroom acoustics standards, both of which were in drafts at the time of the initial application.<br><br>The ICC disapproves the application of the Access Board (November) because the documents are not available, and reschedules the application for May 2010.<br><br>ANSI approves *ANSI/ASA S12.60-2009/Part 2, American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools—Part 2: Relocatable Classroom Factors* (December). |

| | |
|---|---|
| **2010** | ANSI approves *ANSI/ASA S12.60-2010/Part 1, American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools—Part 1: Permanent Schools* (May)<br><br>The International Code Council upheld the prior disapproval of the application of the U.S. Access Board (May).<br><br>The policy board of the U.S. Access Board votes unanimously in support of rulemaking to reference the new ANSI/ASA S12.60-2009/2010 in the ADA and ABA guidelines. A Notice of Proposed Rulemaking (NPRM) will be the next step towards an enforceable rule (July). |

This presentation highlights the advocacy and educational efforts put forth by ASHA designed to achieve classroom acoustics standards applicable to building codes for new school buildings and for renovation of existing school buildings. This advocacy effort has been designed to improve the listening and learning environment in classrooms for both children and individuals with hearing loss.

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# Perception of classroom acoustics and listening tests – a web-based survey

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## INTRODUCTION

Poor listening conditions in classrooms impair speech comprehension, (Klatte et al. 2010) memory (Kjellberg et al. 2008; Ljung et al. 2009; Ljung & Kjellberg 2009) and increase annoyance and the mental effort needed to listen (Shield & Dockrell 2003). Listening conditions are determined by a number of factors but can mainly be attributed to room acoustic qualities, and the background sound determined by outdoor or indoor noise sources. In assessing listening conditions there are several indexes based on room acoustic measures, however, these require measurements on site and are hence expensive and time consuming to carry out. Furthermore a good rating alone may not sufficiently quantify a favorable communication according to Morimoto et al. (2004), that introduced the subjective rating of listening difficulty.

This study was carried out to see whether poor listening conditions could be assessed on a large scale using speech in sound tests, subjective ratings of the classroom acoustics and and/or the teachers' description of the physical room, all administered on the net. We also wanted to find out more on how the pupils experienced their sound environment and whether poor listening conditions could be predicted by their perception of the classroom acoustic and/or the teachers' description of the physical room.

## METHOD

The instructions, questionnaires, and listening test were administered via the internet.

### Listening tests

The pupils listened to sentences with low semantic redundancy (Hagerman 1982) in two signal-to-noise ratios, -3 dB and -6 dB and at two distances.

The choice of signal to noise ratios were selected on the basis of a pilot study carried out in two classes not taking part but of the same age group to get a response around 50 % of the psychometric response scale.

The sentences were played back though loudspeakers connected to a computer or MP3 player, using the schools own playback systems. The loudspeakers were placed at a position where the teacher usually stands when she/he teaches the class. The volume was chosen beforehand to give a comfortable listening level. Before the tests the students were given information and the opportunity to hear one set of the sentences without noise.

Four wave files each with 10 sentences were played back, two had a signal to noise ratio of -3, and two a signal to noise ratio of -6 dB. For the test, the class was divided into two groups, one positioned *close* to the loudspeakers and one *far away* from the loudspeaker. After half of the listening test the groups changed places. Each group hence heard the two conditions in the order of -3 dB and -6 dB twice, one in the position *close* and one in the position far away. In all, there were 4 listening conditions *10 sentences and as every sentence had 5 words the pupils could have 0 to 50 (5*10) correct answers in each listening condition.

### Questionnaire

A questionnaire was distributed after the listening test where the pupils were asked to rate the interference of the sound environment with their ability to: speech, listen and concentrate. They were further asked to describe their perception of the classroom sound environment using the adjectives quiet, clattering, and noisy. The teacher was asked to give a description of the size of the room, the type walls and ceiling, the type of sound absorbents in the ceiling if any, and number of larger scattering objects, such as shelves.

### Participants

Classes at junior high school and grammar schools were invited and 59 classes from 38 schools in Sweden took part. The total numbers of pupils were 1,135 with 49.6 % girls and 49.4 % boys. Of the pupils, 179 (15.8 %) did not have Swedish as their native language, 48 (4 %) had impaired hearing and 4 pupils had hearing aid.

### Analyses

The results from each class were reported as percentages of answers in the various categories, hence no individual analyses of relations etc. could be carried out. Statistical analyses of the data was done using ANOVA when data was numerical and approximately normally distributed, and with Mann Whitney U-test when data was ordinal and/or could not be assumed to be normally distributed.

## RESULTS

### Perception of speech

The average percentages of correct answers for the four conditions are given in Table 1. The results showed that there was a slight effect of distance and that this was not affected by the S/N ratio. The reduction of signal to noise ratio of 3 dB gave a reduction of correct answers with about 25 %. The results also showed that there was a large variation between classes in percentage correct heard words, with one standard deviation ranging from 15 to 20 %.

**Table 1:** Average percentage of correct answers and standard deviation per class and conditions

| Conditions | - 3 dB | - 6 dB |
|---|---|---|
| Close | 66 % (18.7) | 40 % (16.5) |
| Far away | 59 % (20.2) | 34 % (15.4) |

Factors that marginally predicted the speech perception were if the classroom ceiling had hanging absorbent panels, and the pupils descriptions of the classroom as clattering or noisy while the number of children speaking Swedish as their native language, the size of the room, or the number of hard walls did not have a statistically significant influence.

Figure 1 shows the results of the speech perception for the four listening conditions for the classrooms with hanging absorbent panels (n=13) and for the classrooms with absorbent panels directly mounted on the ceilings (n= 31) and the rest (n=5). For the conditions with -6 dB S/N, the classes in rooms with hanging absorbing panels generally performed somewhat better, and a significant difference was seen for the condition close (Z=-2.067, p<0.05).

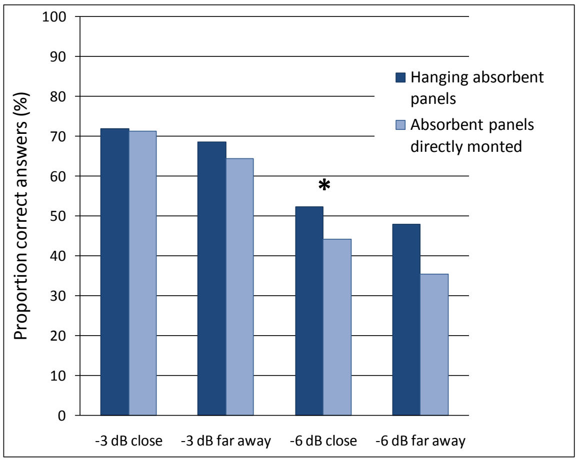



**Figure 1:** The median value of proportion of correct answers for the classroom with hanging absorbent panels and for those mounted directly on the ceiling and the rest

### Subjective reaction of noise interference

In 40 % of the classes there was at least one pupil and in 19 % of the classes there were two or more pupils that *often* had difficulties hearing what the teacher said. Furthermore, nearly all classes or 81 % had one or more student that had difficulties concentrating due to noise.

### Subjective perception of the sound environment in the classroom

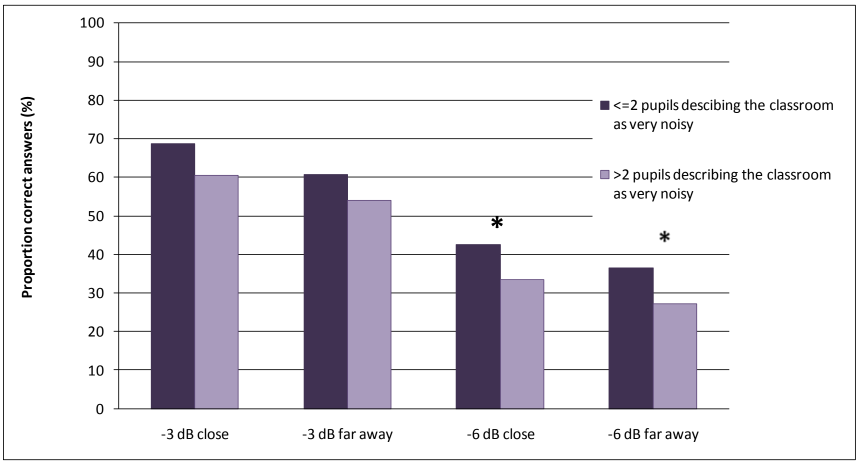
In 33 % of the classrooms there were 3 to 6 pupils rating the classroom as very clattering, and only 14 % of the classrooms had no pupil rating the classroom as very clattering.

In 37 % of the classrooms there were 3-18 pupils rating the classroom as very noisy, and only 19 % of the classrooms had no pupil rating the classroom as very noisy.

### Relation between subjective perception and speech perception

Figure 2 shows the results of the speech perception for the four listening conditions for classes where two or more pupils had reported the classroom as being very clattering (n=19) respectively very noisy (n=21) as compared to classes where less than two pupils had reported the classroom as being very clattering (n=38) respective noisy (n=36).

It can be seen that classes where more than two pupils rated the classroom as clattering and noisy, also generally have a somewhat poorer result on the listening test. Significant differences were found for the conditions with -6 dB S/N, at close distance for both descriptions (F=4.93; p<0.05; F=4.40 p<0.05) and for noisy also for far away (F=4.93; p<0.05).



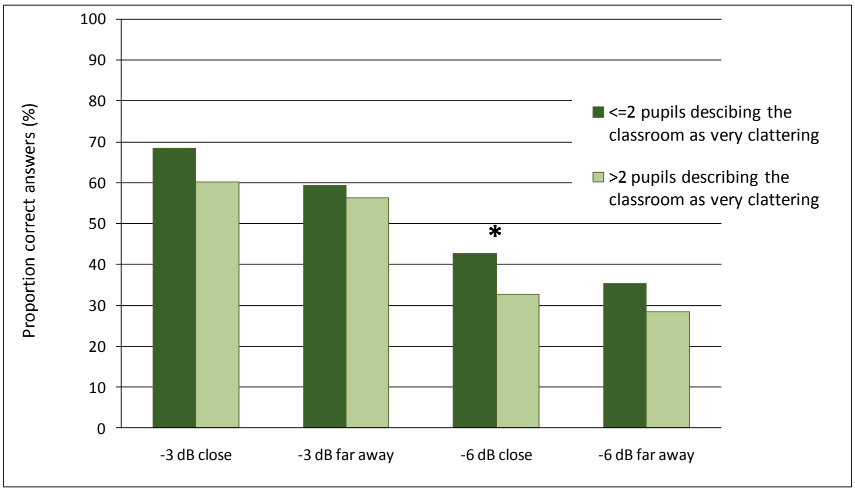




**Figure 2:** Average percentage of correct answers for classes divided into those with more than two respective two or less pupils describing the classroom as very clattering (top figure) and as very noisy (bottom figure)

## CONCLUSION

The study was carried out via the web with for us limited possibilities to control for errors that may occur in performing the study. The way of distribution also means that we have little knowledge on the participating schools and those who chose not to participate, hence general conclusions cannot be drawn. The conclusions are also hampered by the fact that we only got summaries of the results per class, making it impossible to for instance relate individual reactions and perceptions to the results of the listening test.

Nevertheless, the results are from more than 1,000 pupils and give some interesting results on factors that could predict perception of speech in the classroom, such as type of absorbent panels. It is also noteworthy to see that about one fifth of the classes had two or more pupils that *often* had difficulties hearing what the teacher said, and that in nearly all classrooms one or more pupils *often* had difficulties concentrating due to noise. Worth following up in further studies is also the finding that the pupils' own perception of the sound environment was the best prediction of the results of the listening test.

If the method can be validated it opens up for interesting possibilities to screen via the web.

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# Noise and cardiovascular disease: A review of the literature 2008-2011

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ABSTRACT

A systematic literature review identified over 50 peer-reviewed English-language papers on noise and cardiovascular disease published in the period 2008-2011. With respect to environmental noise, we saw an emphasis on road traffic exposures and a significant focus on the issue of co-exposure to noise and traffic-related air pollution. Several studies examined the degree and determinants of these co-exposures, producing an important insight into correlations among these pollutants, which interestingly were not as high as had been expected. Other studies examined the joint effect on human health; the results of these studies were not entirely consistent but suggested independent cardiovascular health effects attributable to both noise and air pollution. Aircraft noise exposure also received considerable attention with the HYENA project maturing and producing several interesting results. Despite the very large potential public health problem associated with over-exposure to noise at work (i.e. given the ubiquity of exposure), occupation studies were still uncommon. Results showed a fairly consistent positive association between work-noise and both hypertension and ischemic heart disease. Finally, a handful of studies was reviewed that dealt with other issues such as policy, methodology and disease mechanisms. In this paper we summarize the progress of research in this field over the past three years, and propose research directions for the future.

METHODS

A literature review was undertaken to identify studies pertaining to the theme of the physiological effects of noise exposure. We searched PubMed using keywords pertaining to noise, transportation, traffic, aircraft, railway, proximity to road; and cardiovascular disease, coronary heart disease, ischemic heart disease, myocardial infarction, hypertension, and stroke. Literature was also hand-searched for additional studies. The search was limited to English language and the period 2008-2011.

INTRODUCTION

Over 50 peer-reviewed English-language papers were identified. This review is primarily bibliographic in nature and papers are presented by exposure, then disease sub- categories.

The association between noise and cardiovascular disease has been studied for several decades and the weight of evidence clearly supports a causal link between the two. Nevertheless many questions remain, such as the magnitude of the adverse effects of noise, whether there are thresholds for effects, how noise and other cardiotoxic pollutants (such as particulate matter) interact in disease causation, whether vulnerable populations exist (such as children or the elderly), or gender-based differences, and how epidemiological study in this area can be improved methodologically (Davies & van Kamp 2008; Babisch 2011). This review will focus on contributions to literature over the past 3 years in the area of noise and CVD in general, but focus on these particular questions; the issue of vulnerable populations is taken up in more detail in a companion review by van Kamp & Davies (2011).

In addition, we refer the reader to several review papers published since 2008, especially those of Babisch (Babisch 2008, 2011; Babisch & van Kamp 2009), Kaltenbach et al. (2008), Pirrera et al. (2010) and, reflecting the European focus of research on the noise and cardiovascular disease, a collection of country-specific reviews published in *Noise and Health* in 2011 (Belojevic et al. 2011; Bluhm & Eriksson 2011; van Kempen 2011; Lercher et al. 2011; Maschke 2011; Stansfeld & Crombie 2011).

## ROAD TRAFFIC NOISE

A key issue in the interpretation of studies of the association of road traffic noise with cardiovascular disease has been in understanding the role of air pollution, that have also been linked to cardiovascular disease (Brook et al. 2010). Noise and air pollution share a major common source – the motor vehicle. If co-exposures are strongly correlated we would anticipate confounding, or effect modification; there is also the possibility that one is simply a “marker” for the effect of the other. This is a particular problem for studies that rely on proximity to roadway as a surrogate for pollutant exposure, i.e. Gan et al. ( 2010).

Several recent studies examined the basic question of correlation between traffic-related air and noise pollution and their findings are summarized in Table 1.

**Table 1:** Correlation between traffic noise and air pollutants (pearson correlation coefficient unless otherwise stated)

| | $NO_X$ | NO | $NO_2$ | Black smoke | UFP* |
|---|---|---|---|---|---|
| Noise | 0.62[a]<br>0.64[b]<br>0.50[c] | 0.41-0.60[d]<br>0.39[e] | 0.53[b]<br>0.62[f]<br>0.16-0.62 [d]<br>0.33 [e] | 0.24[i]<br>0.44** [e] | 0.21-0.60[g]<br>0.22-0.41[d]<br>0.41-0.81[h] |

* Ultrafine particulate; ** Black carbon; [a] (Sorensen et al. 2011); [b] (Davies et al. 2009a, b); [c] (Persson et al. 2007); [d] (Allen et al. 2009); [e] (Gan et al. 2011a - Spearman); [f] (Foraster et al. 2011); [g] (Boogaard et al. 2009); [h] (Weber 2009); [i] (Beelen et al. 2009)

Overall correlations were found to be fairly consistent, generally low to moderate. In addition to those shown in the table, correlations between $PM_{2.5}$ and noise were quite low, perhaps because road traffic is not an important generator of this size of particulate (Gan et al. 2011a; Boogaard et al. 2009). Huss et al. (2010) found low correlation between $PM_{10}$ levels and aircraft noise, perhaps not unexpectedly due to the difference in source (Huss et al. 2010 - Spearman). Interestingly, correlations of modeled estimates (i.e. Gan et al. 2011a; Sorensen et al. 2011) were very similar to comparisons of measured values, even though the air and noise pollution models used a number of the same inputs (traffic volume etc.). The lower than expected correlations are likely due to differences in specific source (i.e. tyre noise vs engine exhaust pollution) and propagation paths; key determinants of variability seem to relate to traffic density, and meteorological conditions (Allen & Adar 2011; Davies et al. 2009a, b; Foraster et al. 2011).

The results of prior studies of road traffic noise and hypertension (HT) have been called “extremely heterogeneous” (Babisch 2006). Barregard et al. (2009) noted problems with study design as a possible cause of this heterogeneity (e.g. cross-sectional design, lack of control of confounders). Their own study examined both prevalence of physician-diagnosed HT and incidence (using data on residential histories, and date of diagnosis) in a cohort of 1,953 adults in Lerum, Sweden. Information on potential confounders was collected by questionnaire; noise exposures were modeled. Increases in prevalence odds ratio were primarily evident in men; for HAT, prevalence odds ratio (POR) was 1.2, (95%CI 0.7-2.1) and for use of hypertensive medications, POR=1.5 (0.9-2.7). Men's POR increased greatly if analysis was restricted to >10 yrs in residence to 3.8 (1.6-9.0). Incidence rates of HT in males gave similar results, with a RR=1.3 (0.7-2.3) increasing to 2.9 (1.4-6.2) for >10 years in the same dwelling.

Belojevic et al. (2008) suggested that heterogeneity in findings may result in part from poor validity of exposure measures, suggesting the use of night-time road traffic noise exposure data may be less biased. They used measured night-time noise data from 70 downtown streets in Belgrade to assess exposure in a cohort of 2,503 adults, who had lived in the same residence for >10 years, and who slept on the street side of the house. Cases were those who were on HT medication or had measured BP >140/90 mmHg. HT prevalence was 19.2 %; the adjusted prevalence odds ratio was increased in men, but not women. For men exposed >45 dBA vs. <45 dBA the POR was 1.58 (1.03-2.42).

Bodin et al. (2009) focused on age as an interaction or effect modifier in the road traffic noise – HT relation. They used modeled exposure levels, and self-reported HT definition; risk of HT was "modestly" increased at levels <60 dBA ($L_{eq,24hr}$), and increased above 60 dBA. No gender differnces were noted. An age effect was seen with greatest risks seen in the "middle aged (40-59 years) compared to younger (18-39) or old-aged (60-80 years). Chang et al.'s (2010a, b) cross sectional study examined road traffic noise and HT in Taiwan, concerned about the generalizability of prior studies that had mostly been restricted to European cities. This was highly exposed population compared to prior studies, with a 90 % exposed above 75 dBA ($L_{eq,8hr}$ at residence). Overall adjusted prevalence odds ratio was 2.15 (95%CI 1.08-4.26) in those exposed over 80 dBA. In males only, a dose/response in prevalence was observed over 4 noise categories from <77 to ≥83 dBA.

The Hypertension and Exposure to Noise near Airports (HYENA) study provided interesting data in a series of papers on the effects of road traffic noise in their study of exposures around 6 major European airports (Floud et al. 2011; Haralabidis et al. 2008; Jarup et al. 2008; Selander et al. 2009a, b). Adjusted risk of HT was estimated at 1.097 (1.003-1.201) per 10 dB increase in road traffic noise (Jarup et al. 2008). A gender difference was apparent with a more pronounced dose-response relation for men, reaching OR=1.5 for those exposed ≥67.5 dBA. The gender difference was also apparent when hypertensive medication use was examined in this study group. Among a subset of 4,642 subjects, overall use of anti-hypertensive medications was not associated with road noise exposures, though an effect modification with age was apparent for men only (and not statistically significant) (Floud et al. 2011). Haralabidis et al. (2008) using 24-hour blood pressure profiles in a subset of 149 of the HYENA subjects, showed that exposure to road traffic noise at night was associated with an adverse reduction in the normal diastolic blood pressure "dipping". "Non-dipping" has been previously identified as a "...persisting consequence of major traumatic events.." and may be an independent risk factor for CVD (Haralabidis et al. 2008). Using similar methodology, Haralabidis et al. further showed that regardless of noise source, increased night time noise had an acute effect on both systolic and diastolic BP, supporting the hypothesis that habituation to noise while sleeping is incomplete.

In other sleep studies, Griefahn et al. (2008) showed increased heart rate evoked by noise exposure in the range 45-77 dBA, with and without awakening; further, responses did not diminish during the night, further experimental evidence of incomplete habituation to noise during sleep. Similarly Tassi et al. (2010a, b), studying subjects who were chronically exposed to noise from railways, found that those chronically exposed at home to rail noise did have fewer awakenings, but they also found some degree of cardiovascular habituation that involved interactions with age and exposure duration. The cardiovascular effects of train noise at night seemed to be greatest for freight trains, and the effects greater among younger subjects (Tassi et al. 2010a, b). Graham et al. (2009) found night-time exposure at home to be negatively associated with parasympathetic tone, but found no association with sympathetic tone. Selander et al. (2009a, b) examined the relation between exposure to road traffic noise and morning cortisol levels in a subset of 439 of the HYENA cohort, but no obvious association was found.

Three studies examined simple proximity of residence to major roads and cardiovascular effects; this study design has an inherent limitation that complicates identification of the causal agent. Gan et al. (2010) showed that in a large cohort study in the Canadian city of Vancouver, compared to subjects who constantly lived further from traffic, those who constantly lived closer had an increased risk for coronary heart disease mortality (CHD; RR=1.29, 95%CI 1.18-1.41). During a 5-year window those who moved closer to traffic and those who moved away from traffic had intermediate levels of risk (1.20 and 1.14, respectively). Hoffman et al. (2009) in the Heinx-Nixdorf study showed that CHD risk was increased by 50-70 % in those living closer than 100 meters from a major road compared to those living over 200 m away. van Hee et al. (2009) showed that adults living very close to major roads had an increase in the left ventricular mass index (LVMI) of 1.4 $g/m^2$, equivalent to an increase in systolic blood pressure of 5.6 mmHg. This difference was not associated with $PM_{2.5}$ levels however, and all of these studies acknowledge the difficulty in attributing cause to specific agents and identify noise as one such potential agent, along with air pollutants.

Three studies looked specifically at road traffic noise and heart disease. All of these also examined joint effect of noise and air pollution; these latter findings are discussed below. Gan et al.'s (2011a) study of CHD mortality used a population-based cohort of 412,420 adults aged 45-85 yrs, and modeled noise exposures. They found a 9 % (95%CI 1 %-18 %) increase in CHD mortality associated with a 10 dB(A) increase in residential noise (all sources, $L_{DEN}$). There was little dose-response trend evident, but those exposed in the highest noise group [$L_{DEN}$ > 70 dBA] had a RR of 1.30 (95%CI 1.12-1.51). Beelen et al. (2009) investigated several CVD mortality endpoints in the Netherlands Cohort Study on Diet and Cancer using modelled noise levels. The cohort size was 117,528 (with 6,137 cases). For the highest noise exposure category (>65 dBA $L_{DEN}$) relative risk (adjusted) increased for all CVD (1.25, 95%CI 1.01-1.53) and of heart failure (1.99, 1.05-3.79). Risk of ischemic heart disease and dysrhythmia were also elevated (1.15 and 1.23 respectively) but neither was statistically significant. Selander et al. (2009a, b) examined risk for acute myocardial infarction (MI) morbidity in the Stockholm Heart Epidemiology Program. Subjects were 5,452 adults 45-70 years; noise exposures ($L_{Aeq,24h}$) were modeled. For subjects exposed over 50 dBA the RR was 1.12 (95%CI 0.95-1.33). When the study sample was restricted to reduce exposure misclassification, RR increased to 1.38 (1.11-1.71).

With respect to the joint effect of traffic-related air and noise pollution on CVD, the findings of these three studies were similar: that each pollutants seemed to have independent effects on CVD outcomes (Beelen et al. 2009; Gan et al. 2011a; Selander et al. 2009a, b). Selander et al.'s effect estimate (1.12, see previous paragraph) was already adjusted for $NO_2$ exposure level; unadjusted estimates were not reported. When they examined interaction through stratification, each exposure appeared to be independently capable of increasing risk but no interaction was evident. In Gan et al.'s models, adjusting for air pollution ($PM_{2.5}$, $NO_2$ and black carbon) did reduce the noise effect estimate (from 1.30 to 1.22) with black carbon having the greatest effect. However, in contrast to Selander et al. a simple additive interactive effect for noise and black carbon was seen (Gan et al. 2011a). Finally, Beelen et al. (2009) did not examine interactive effects; but after adjusting for air pollution (black smoke) in noise models risk estimates for noise effects were reduced, but not extinguished (i.e. all CVD was lowered to 1.17, IHD to 1.01). That of heart failure only dropped as far as 1.90, but became borderline significant (95%CI 0.96-3.78).

Stroke has not been widely examined with respect to noise exposure despite the fact that hypertension is an important risk factor. Sørensen et al. (2011) studied this relation in a Danish cohort of 57,053. They found road traffic noise ($L_{DEN}$) was positively associated with incidence of stroke, with a relative risk of 1.14 (95%CI 1.03-1.25). Risks were only found in those aged over 64.5 years, but in this group there was a clear dose-response relation with elevated risk beginning between 55 and 60 dBA.

Finally, Sobotova et al. (2010*)* showed that exposure to road traffic noise was associated with elevations in risk factor scores from predictive models such as the European Society of Cardiology's relative risk HeartScore®.

## AIRCRAFT NOISE

Babisch & van Kamp summarized the literature on aircraft noise and hypertension in 2009. They concluded that there was sufficient evidence of association between aircraft noise and hypertension but that only a "best guess" quantitative effect estimate could be made (they recommended an odds ratio of 1.13 [95% CI 1.00-1.28]). In 2008 Jarup et al. published the first in a series of papers resulting from the HYENA study investigating the link between noise near airports and hypertension (also Eriksson et al. 2010; Floud et al. 2011; Haralabidis et al. 2008, 2011; Jarup et al. 2008). This study used modeled exposure data for aircraft noise, measured blood pressure levels and collected supplementary data on potential confounders and effect modifiers from 4,861 people living around six major European airports. A dose-response pattern for hypertension (using WHO definition SBP/DBP > 140/90 mmHg) was evident for the noise metric $L_{night}$ but not $L_{Aeq,16hr.}$ Odds ratios increased by 1.14 (95%CI 1.01-1.29) per 10 dB increase (Jarup et al. 2008). Floud et al. (2011) used the same study population to examine antihypertensive use related to aircraft noise exposure. Results varied by country; they were generally positive for both $L_{night}$ and $L_{Aeq,16hr}$, but were only significant for the UK (both metrics) and the Netherlands ($L_{night}$ only); estimates ranged up to OR=1.35. There was no apparent gender effect. The authors concluded "…results were more consistent for across countries for prescriptions for other stress-related conditions" including anaxiolytics. In Haralabidis et al.'s two papers investigating 24-hour ambulatory blood pressure monitoring in a sub sample of 140 subjects, no effect was found of aircraft noise on night-time dipping (except in Athens, where the number of aircraft event and $L_{Aeq,\ night}$ was higher), (Haralabidis et al. 2011) but blood pressure increased - SBP by 6.2 mmHg, DBP by 7.4 mmHg - during 15-minute measurement intervals in which there was an aircraft event (Haralabidis et al. 2008). Finally, Selander et al. (2009a, b) found that in a sub-set of 439 HYENA subjects, morning cortisol levels were elevated in those exposed to aircraft noise at night, but in women only and that the increase was greatest among those women who were employed.

Most aircraft noise studies focus on civilian aircraft. Rhee et al. (2008) however examined the association between exposure to military aircraft noise (helicopters and fighter jets) in Korea. Exposed subjects lived with 5 km of either a helicopter base ($L_{Aeq,8hr}$ 71-72 dBA) or a fighter jet base (68-82 dBA), for a minimum of 10 years; they were compared to “non-exposed” control group. HT was defined as physician diagnosed HT, BP >140/90, or use of antihypertensives. Risk was elevated in both exposed groups (OR=1.62 and 1.23 for helicopter and fighter, respectively) but only that for helicopter exposure was statistically significant.

Gender specific effects were the focus of Eriksson et al. (2010) They examined cumulative incident HT (physician diagnosed HT or BP >140/90) in 4,721 subjects exposed to noise from Stockholm airport, and who were followed for 8-10 years. Elevated risk for HT was apparent in only males. Estimated risk estimates increased when the analysis was restricted to non-smokers.

Huss et al. (2010) examined the association of aircraft noise with Acute MI mortality, taking into account co-exposure to air pollutants. Four point six million subjects of the Swiss national cohort were followed for 5 years. Noise ($L_{DN}$) and $PM_{10}$ levels were modelled. In their fully adjusted model containing both pollutants plus distance of residence from major road, they found a 50 % increase in AMI mortality in those exposed $L_{DN}$ > 60 dBA. $PM_{10}$ was not linked to increased risk, but residing with 100 meters of a major road increased risk approximately 18 %. Huss et al. found no link between aircraft noise exposure and stroke mortality in this study.

## OCCUPATIONAL NOISE

Two cohort studies of occupational exposure and hypertension were reported in this period (Lee et al. 2009; Sbihi et al. 2008). Sbihi followed a cohort of over ten thousand sawmill workers for an 8-year period. Cases were identified from physician billing and hospital discharge records, and exposure based on work history data and a job-exposure matrix, described separately (Davies et al. 2009a, b). Eight hundred and twenty eight cases were identified; cumulative occupational noise exposure was a strong predictor of risk of hypertension, with a relative risk of 1.32 in the highest exposed population (>115 dBA*year) compared to controls (<95 dBA*year) and there was a significant dose response trend. Trends of duration of exposure at different thresholds were inconsistent. The authors attributed this to misclassification of exposure potentially due to the unmeasured effect of subjects wearing hearing protection (HPD, Friesen et al. 2008). This was addressed by later work by Sbihi et al. (2010a, b) examining methods for adjusting measured noise exposures for HPD use in retrospective studies. Lee et al. (2009) followed 530 male metal manufacturing workers for nine years, obtaining annual blood pressure measurements. They categorized exposure groups as (I) intermittent, unprotected, (II) <85 dBA (TWA), single HPD protection and (III) >85 dBA, double protection. A control group consisted of office workers (<60 dBA). Systolic, but not diastolic, blood pressure increased over time in all three exposed groups, in a dose-response fashion; 1.7, 2.0 and 3.8 mmHg for groups I, II, and III respectively.

Chang et al. (2009, 2010a, b) examined the role of workplace noise exposure and co-exposure to organic solvents (N,N-Dimethylformamide and Toluene) in a pair of studies. In the first, cross-sectional, study 59 workers in a synthetic leather plant were categorized as noise only, solvent only or co-exposed (using 'cut-points' of 80 dBA, and a solvent hazard index of 0.1). Subjects exposed to either noise or solvent showed greatly increased risk of hypertension, 7-8 fold when compared to a non-exposed control group, but co-exposure to both pollutants did not significantly increase this risk. In the second study, twenty subjects were divided into 4 similar exposure groups (none, noise-only, solvent only and combined) and undertook 24-hour ambulatory blood pressure monitoring. Only combined-exposure showed significantly elevated blood pressure (for diastolic only, both working hours [21mmHg] and 24-hours [16 mmHg]). Work time DBP were non-significantly elevated for noise only (13 mmHg) and solvent only (9 mmHg). Both studies were challenged by small numbers, cross-sectional study design and weakly controlled confounding.

Tomei et al. (2010) undertook a meta-analysis of studies of noise and hypertension, heart rate and ECG abnormalities. Fifteen studies yielded a total of 18,658 subjects. These were categorized as low (mean 62 dBA), intermediate (mean 85 dBA) or highly exposed (mean 92 dBA). Positive results were found for all hypothesized associations (systolic BP, diastolic BP, heart rate, and ECG abnormality). The odd ratio for overall prevalence of hypertension was 2.56 (95% CI 2.01-3.23).

Gan et al. (2011b) undertook a secondary data analysis of the US national Health and Nutrition Examination Survey (NHANES) to study noise-CVD links across a broad range of industries. Cross-sectional in design, data for 6,307 subjects aged 20 years and over were assessed for noise exposure at work (using self-report of having to raise voice to be heard). A variety of outcomes were examined including self-reports of physician-diagnosed cardiovascular disease, measurement of blood pressure and several biomarkers. Excess risk was observed for angina pectoris, myocardial infarction and coronary heart disease, with odds ratios of 2.9, 1.6 and 2.0, respectively. Dose-response trends were statistically significant for angina and CHD. Risks for CHD were stronger in younger age groups, current smokers, and in men. Noise was also associated with isolated diastolic BP (DBP>90 mmHg, SBP<140 mmHg), but not with any other BP measures or any biomarkers (including total cholesterol, HDL-cholesterol, LDL-cholesterol, triglycerides, circulatory inflammatory markers (i.e. C-reactive protein), homocysteine or plasma glucose.

## SUMMARY

The last ICBEN congress review identified several areas for future research (Davies & van Kamp 2008). Several of these have been addressed in recent papers. Important progress was made on "untangling" the CVD effects of traffic co-exposures, noise and air pollution (TrAP). Several studies examined correlations of the two exposures, and determinants of variability. These showed us that the correlations were not as high as many researchers anticipated, and that epidemiologic studies of joint effects should be successfully pursued. Four large joint effects studies were reviewed here, and they were consistent in suggesting that both air pollution and noise are likely independent risk factors for CVD. This is consistent with several other lines of evidence, such as that of animal and occupational studies - that are less susceptible to confounding - and with the fact that plausible biological mechanisms exist for both exposures (Allen & Adar 2011).

With respect to effects of gender on health associations, the majority of the studies found men to be at greater risk than women for noise-related cardiovascular disease irrespective of noise source (road vs aircraft) or outcome (HT or heart disease). Exceptions were the studies of Selander (cortisol response), Bodin (self-reported HT) and Sorenson (stroke) (Bodin et al. 2009; Selander et al. 2009a, b, 2011). Jarup et al. (2008) found men at greater risk in their main analysis, but only women, when the sample was restricted to those aged over 65 years. Other issues regarding vulnerable populations are reviewed in van Kamp and Davies in this volume (van Kamp & Davies 2011).

Results regarding effect levels (thresholds) were fairly consistent. For hypertension lowest observable effect levels (LOEL, for road taffic noise) were reported at between 50 dBA ($L_{Aeq,24hr}$ Jarup et al. 2008) and 60 dBA ($L_{Aeq,24hr}$ Barregard et al. 2009; Bodin et al. 2009); response to noise at night was seen at lower levels: 45 dBA ($L_{Aeq,night)}$ Belojevic et al. 2008) and 40-44 dBA (Jarup et al. 2008). Heart disease responses were seen as low as 50 dBA (($L_{Aeq,24hr}$ Selander et al. 2009a, b) to 65 or 70 dBA ($L_{DEN}$ Gan et al. 2011a; Beelen et al. 2009). Eriksson et al. 2010 and Huss et al. (2010) both identified LOEL for aircraft related noise for HT ($L_{DEN}$) and AMI ($L_{DN}$) respectively, at 60 dBA.

Generally speaking the methodological quality of the studies reviewed was high, especially compared to many of the early efforts in this field. The problem of misclassification of exposure has been addressed by the work on TrAP/noise correlation and in the occupational arena by the work of Sbihi et al.. It was encouraging to see other work on potential co-exposures such as organic solvents (Chang et al. 2009) Effects of joint-exposures are generally poorly studied in occupational epidemiology.

With respect to future research, reviewers are consistent in their call for more prospective studies to help elucidate underlying mechanisms of disease and the study of children, where results have been inconsistent (Basner et al. 2010; Babisch 2011; Bluhm & Eriksson 2011; Maschke 2011; Stansfeld & Crombie 2011).

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# Noise and health in vulnerable groups: a review

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## ABSTRACT

Vulnerable or susceptible groups are mentioned in most reviews and documents regarding noise and health. But only a few concrete and focused studies address this issue. Groups at risk most often mentioned in the literature are children, the elderly, the chronicly ill and people with a hearing impairment. Another distinction encountered is that of sensitive people, shiftworkers, people with mental illness, people suffering from tinnitus, schizofrenia or autism and foetuses and neonates. The mechanism for this vulnerability has not been clearly described, and relevant research has seldom focused on the health effects of noise in these groups in an integrated manner. This paper summarizes the outcomes and major conclusions of a systematic, qualitative review of studies over the past five years. The full review will be published elsewhere. Evidence is descibed along effects and groups assumed to be at risk.

## INTRODUCTION

In the recently pusblished guideline by WHO (2011) for the burden of disease from environmental noise it is concluded that future epidemiological noise research will need to focus on vulnerable groups; some noise exposures may be worse for particular subgroups than for others such as children, older people and lower socioeconomic groups. This conclusion supports the notion that noise effects can and should be differentiated between subgroups. In most recent reviews (Clark & Stansfeld 2007; Berry & Flindell 2010; Davies & van Kamp 2008; WHO 2000, 2011) on noise and health, this topic has been touched upon, but evidence is still scarce or scattered. There are conceptual problems and the mechanism for this vulnerability has not been clearly described, nor are the mechanisms necessarliy the same for different groups at risk.

## METHODS

### Data sources and searches

Medline and Scopus were searched to detect relevant peer reviewed studies published between January 2006 and April 2011. There was a language restriction for English, French and German papers. A wide range of keywords was used, related to noise exposure, vulnerable goups and health outcomes, which are presented in Table 1. In addition, the reference sections of previous systematic reviews, key papers, conference proceedings and international reports on vulnerable groups as well databases of websites dealing with the issue of noise and vulnerability (WHO, PINCHE, ENNAH) were checked for potentially relevant references.

### Inclusion and quality criteria

All studies were selected that concern environmental quality in relation to noise and susceptible groups. Studies which did not explicitly deal with effects were in most cases excluded.

**Table 1:** Key search terms

| | |
|---|---|
| **Health outcomes** | **adverse effects, health**./ or health status/ or mental health/ or public health/ **stress related effects** or asthma or respiratory or blood pressure or heart rate* or cardiovascular). stress, psychological/ or stress, physiological/ or emotions/ or asthma/ or child behavior/ or blood pressure/ or heart rate/ **cognitive effects, performance or cognitive impairment** cognitive development, memory, recognition, pre-reading or school performance or performance or comprehension or annoyance or (disturbance adj3 daily activity*) or emotion* or stress or speech or intelligibility).tw. cognition/ or cognition disorders/ or memory/ or reading/ or mental recall/ or recognition, psychology/ or loudness perception/ or comprehension/ or speech intelligibility/ or hearing disorders/ (**sleep or insomnia or awakening***).tw. or exp sleep/ or exp sleep disorders/ or sleep deprivation/ or wakefulness/ (reproductive outcome or pregnancy outcome or birth weight).tw. or pregnancy outcome/ or birth weight/ **vulnerable group*** or vulnerability or frail or child* or infant* or adolescent* or preschool or school* or students or newborn or neonat* or perinat* or prenatal or foet* or fetal or fetus or pregnant or pregnancy or elderly or old people or elder people or mentally ill* or mentally handicapped or mentally disabled or chronic disease* or chronic illness* or shiftworker* or shift worker*). vulnerable populations/ or child/ or infant/ or adolescent/ or students/ or schools/ or pregnancy/ or aged/ or frail elderly/ or disabled persons/ or mentally disabled persons/ or mentally ill persons/ or hearing impaired persons/ tinnitus/ or hearing impaired persons/ or autism/ or (hearing impairment* or hearing impaired or hearing ability or noise sensitiv* or tinnitus or autism). |
| **Exposure:** | noise/ traffic or transport* or road or road-traffic or road-transport or automobile* or vehicle* or vehicular movements or motorcycle* or tram or train or trains or railway* or railroad* or airplane* or aeroplane* or aircraft* or airport* or air-traffic or nightflights or night flights). |
| **Design** | No restrictions |
| Time period | 2006 – 2011 |

RESULTS

### Study characteristics

The original literature search has yielded 212 papers, of which 71 were a priori eligible to be included in the review, based on the crude criteria described above. Eventually, several papers were not inlcuded because they did not give any information on effects. Thirty seven of these studies pertained to primary school children, fifteen to (young) adolescents, two to preschool schildren and four to neonates. A few papers concerned effects of noise in specific patient groups such as children with autism (2) Asthma (1) and ADHD (1). The eldery were addressed in four papers and another four addressed all age groups and/or life span exposures. Remarkably few studies dealt with noise sensitivity, while this may be key to understand susceptibility, sensitive moments of the day, sensitive places and sensitive periods in the life course. An additional search in MEDLINE and Scopus yielded eight studies on these related topics for the past five years.

## Definitions

**Vulnerability** refers to the susceptibility of a person, group, society or system to physical or emotional injury or attack. It has also been described as the degree to which people, property, resources, systems, and cultural, economic, environmental, and social activity is susceptible to harm, degradation, or destruction on being exposed to a hostile agent or factor.

**Noise sensitivity** refers to the internal states (be they physiological, psychological and attitudinal, or related to life style or activities) of any individual, which increase their degree of reactivity to noise in general. Noise sensitivity has a strong genetic component as was shown by Heinonen et al. (2005). Noise sensitivity can also be caused by physical illness such as: constant migraine headaches and sudden trauma, such as a head injury. Severe panic disorder may also be accompanied by oversensitive hearing, which in turn facilitates panic attacks. Ear infections, surgery, and the use of some prescribed medications can also lead to this heightened reaction to noise.

In epidemiology **a high risk group** has been defined as a group of people in the community with a higher-than-expected risk for developing a particular disease, which may be defined on a measurable parameter, an inherited genetic defect, physical attribute, lifestyle, habit, socioeconomic and/or educational feature, as well as environment (McGraw-Hill Concise Dictionary of Modern Medicine 2002).

**Noise sensitive areas**: An area or place is defined as noise-sensitive if noise interferes with normal activities associated with the area's use. Examples of noise-sensitive areas include residential, educational, health, and religious structures and sites, and parks, recreational areas (including areas with wilderness characteristics), wildlife refuges, and cultural and historical sites where a quiet setting is a generally recognized feature or attribute (FAA).

## Who are at risk and at risk for what?

Most often mentioned risk groups in the literature are: children, older people, chronic ill people, and hearing impaired people. Groups potentially also at risk are noise sensitive people, people suffering from tinnitus, shift-workers, mentally ill people (schizophrenia, autism) and foetus and neonates. Health effects most frequently described are annoyance, sleep disturbance, cardiovascular disease and cognitive effects. The overview of evidence is structured along these endpoints and per theoretical risk group.

### *Annoyance*

Van Kempen et al. (2009) showed that the exposure–annoyance curve of schoolchildren (aged 9-11) for aircraft noise, overall has the same pattern as in adults. However, children score lower on annoyance at the high end of the scale and somehwat higher at the lower end. These findings confirm the conclusion of Babisch (PINCHE, 2006). In a recently published study Babisch et al. (2010) concluded that German children between 8 and 14 were considerably less frequently annoyed by road traffic noise at home than adults.

Very few studies are available on annoyance reaction in older people. There is no evidence that people above 60 respond differently to environmental noise (van Kamp et al. 2009). Based on analysis of a large meta data set of TNO (N=62,983) van Gerven et al. (2009) found evidence of a non-linear relation. Results revealed an inverted U-shaped pattern for both road and air traffic noise. The largest number of highly annoyed individuals was found in the middle-aged segment of the sample. With a peak around 45 years and the lowest percentages of highly annoyed in both the youngest and oldest groups. These effects were independent of noise levels and noise sensitivity.

A study in Beijing (Li et al. 2008) among students revealed, that the extremely high levels of exposure to traffic noise (64.0 dBA - 79.2 dBA resulted in a percentage highly annoyed of up to 39 % on the ISO verbal annoyance scale, and 50 % according to the numerical scale.

### *Sleep disturbance*

Evidence has indicated (Öhrström et al. 2006) that children are less sensitive for awakenings and sleep cycle shifts, but more sensitive for physiological effects such as blood pressure reactions (Muzet 2007; Bruni et al. 2011) and related motility (WHO, 2009).

Muzet (2007) concluded in his review, that there is only anecdotal evidence that older people are more at risk for sleep disturbance due to noise. Other potential vulnerable groups are people with a somatic or mental disorder, and shiftworkers (Muzet 2007). Earlier suggestions that long term health effects of sleep disturbance depend on the person's vulnerability and/or sensitivity (WHO 2000; van Kamp et al. 2004; Staatsen et al. 2004) are not supported by more recent evidence.

### *Cardiovascular effects*

Analysis on the pooled data set (Heathrow, Schiphol) of the Ranch study (van Kempen et al. 2006) indicated that aircraft noise exposure at school was related to a statistically non-significant increase in blood pressure and heart rate in children. Road traffic noise did show an unexplained negative effect. Babisch & van Kamp (2009) concluded on an inconsistent association between aircraft noise and children's blood pressure. In their recent review Paunovic et al. (2011) conclude on a tendency towards positive associations, but observed large methodological differences between studies. A review of UK studies (Stansfeld & Crombie 2011) again concluded on inconsistent associations of aircraft noise with systolic blood pressure in children. In a study among children aged 8-14 by Babisch et al. (2009) concluded that road traffic noise at home as stressor could affect children's blood pressure. There is some evidence that short term cardiovascular reactions during sleep are more pronounced in children (Griefahn et al. 2008). Lepore et al. (2010) concluded that compared to quiet-school children, noisy-school children had significantly lower increases in blood pressure, when exposed to either acute noise or non-noise stressors, indicative of a generalized habituation effect. Studies in Servia (Belojevic et al. 2008, 2011) among schoolchildren and preschool children indicated a raised BP among children from noisy schools and quiet residences, compared to children from both quiet environments. There is no consistent evidence that the effect of traffic noise on cardiovascular diseases is greater in older than younger people (Griefahn & Basner 2008). Bodin et al. (2009) found strong evidence for an age effect in the noise BP association, with a stronger relation in the middle aged; age group-specific models could account for differences in prevalence in future studies.

A study among 30 male and female participants aged 18-32 (Chang et al. 2009) concluded that environmental noise leads to a significant increment in both systolic and diastolic blood pressure. The effects were significantly associated with an increment of 5 dBA both in transient as well as sustained effects (lag time > 30-60 minutes) especially in females.

There is a differential, but inconclusive effect regarding gender differences in cardiovascular effects of noise (Davies & van Kamp 2008; Babisch 2006). Babisch (2006) showed that people with prevalent chronic diseases run a slightly higher risk of heart diseases as a result of traffic noise than those without.

### *Physiological effects and quality of life*

A study in France (Mir 2008) among 10 year old schoolchildren showed that school noise exposure was associated with fatigue, headaches and higher cortisol level indicative of a stress reaction. These finding are supported by a Swedish study (Wålinder et al. 2007) who found increased prevalence of fatigue, headache and reduced diurnal cortisol variability in relation with classroom Leq during schoolday levels between 59 to 87 dBA. A cross sectional study in Nigeria (Ana et al. 2009) among children frequenting a school near a major road (noise range: 68 – 85 dBA) found at least some disturbance in 70 % of the children. Fatigue and lack of concentration came forward as the most prevalent noise related health problems.

Parra et al. (2010) report that in people over 60 living in Bogota, among other neighbourhood features, road traffic noise was negative related with both the physical and mental dimension of the HR quality of life.

### *Cognitive effects*

Based on the Ranch study around three major European airports Clark et al. (2006) reported that exposure at home was highly correlated with aircraft noise exposure at school and demonstrated a similar linear association with impaired reading comprehension after adjustment for a range of confounders. Stansfeld et al. (2010) conclude that night exposures does not add to these effects of daytime exposures to aircraft noise. Likewise, Kaltenbach et al. (2008) found exposure to aircraft daytime noise of 50 dBA and over to be associated with learning difficulties in schoolchildren. Road traffic noise exposure at school was not associated with reading comprehension in the RANCH study. Ljung et al. (2009) concluded that road traffic noise impaired reading speed and basic mathematics, but had no effect on reading comprehension or on mathematical reasoning. Irrelevant speech did not disrupt performance on any task. Klatte et al. (2007) did find that serial recall of visually presented digits was severely disrupted by background irrelevant speech. Train noise exposure did not show comparable effects. A later study (Klatte et al. 2010) replicated these findings. Noteworthy is that the children did not consciously realize these detrimental effects.

Shield and Dockrell (2008) related in- and outside noise exposure at school with standard test on literacy, mathematics, and science in children aged 7-11 in London. Results revealed an association between noise and performance on these tests, after adjustment for socio-economic factors, especially in the older children. However, a recent study of Xie et al. (2011) in secondary schools in Greater London did not support these findings.

In a small study (N=20) on the effect of climate, light and noise in the work environment Fosnaric & Planinsec (2008) found a significant effect of noise on work performance of male adolescents.

### *Hearing disorders and impairment*

Studies on hearing loss in children are rare. Within the framework of the PINCHE project Bistrup et al. (2006) do conclude that noise can have auditory effects on children, but most effects are long-term and cumulative. They advise to describe the effects of noise on children in a life-course perspective, in order to illustrate the prospects of cumulative effects. A study (Rocha et al. 2007) among children of highly noise exposed mothers during pregnancy showed no hearing impairment.

In the past five years several studies addressed the issue of hearing disorders and loss in adolescents as a result of recreational noise. Rosanowski et al. (2006) found no pure tone hearing loss, but transient effects on hearing and tinnitus immediately after exposure. Martinez-Wbaldo Mdel et al. (2009) report high frequency hearing loss in 21 % of the highschool students in Mexico, primarily related to frequent exposure to music at discotheques and pop-concerts, the use of personal divices and noise exposure in school workshops. A study in Brazil (Zocoli et al. 2009) among young adults confirmed these findings, indicating that a substantial percentage of the participants reported temporary tinnitus (69 %) after attending disco's, concerts, and listening to music through headphones. Tinnitus complaints were more frequent among females (41 %) than males (27 %). A similar study in Turkey (Bulbul et al. 2009) also found a high prevalence of (transient) tinnitus in young adolescents due to loud music. Noise induced hearing loss at a young age due to recreational music and personal devices was reviewed by Harisson (2008). An American study (Holmes et al. 2007) revealed a prevalence of approximately 6 % perceived hearing loss, and 13.5 % of prolonged tinnitus.

The effects of noise and smoking were studied in a stratified sample of 440 people between 21 and 50 years by El Zir et al. (2009). Results showed an effect of smoking on hearing in all age groups and an interaction effect with noise only in the group older than 40.

In a recent study of Heinonen et al. (2011) noise sensitivity was associated with self-reported hearing disability among all subjects, but especially in women and younger subjects (50 years or less). Baur et al. (2009) reported significant negative effects of noise exposure, painkillers, overweight, and cardiovascular diseases on hearing loss. A positive effect of moderate alcohol consumption was shown in the elderly.

### *Miscellaneous outcomes for specific risk groups and outcomes*

Linares et al. (2006) studied hospital admissions of children younger than 10 years old and found an association between road traffic noise levels and admission for respiratory disease, pneumonia and organic diseases after adjustment for air pollution effects, meteorological circumstances, influenza epidemics and pollen concentrations. A SES effect could not be ruled out, based on the presented information. In a birth cohort of 652 children Bockelbrink et al. (2008) found an association between noise annoyance (specifically during the night) and prevalence of asthma attacks (doctor diagnosed) in girls.

The few studies (Lasky & Williams 2009; Byers et al. 2006; Liu 2010) on neonates at the ICU of hospitals have concentrated on noise levels only and potential measures to reduce these. About the short and long term effects no data are available.

Russo et al. (2009) compared speech evoked responses between normal children and children with autism, under a quiet and noisy condition. Normal children showed delayed reaction times under the noisy conditions, whereas autistic children showed delayed times under both conditions; ADS children perform as well under quiet conditions as normal children do under noisy conditions.

### *Role of noise sensitivity*

Berry and Flindell (2009) conclude in their review that evidence shows that noise sensitive people (NS) are more susceptible to cardiovascular effects. This also ties in with the role of annoyance as a mediating factor. Babisch et al. (2009) only found an effect of NS on cardiovascular effects when NS, annoyance and exposure were assessed before the CVD outcomes (prospective studies). White et al. (2010) compared physiological effects of task performance between highly a NS and non sensitive group in opposite direction. Both mean heart rate and sympathovagal balance of LNS subjects were responsive to the change in circumstances between conditions. This was not the case for HNS participants. Shepherd et al. (2010) found that NS was associated with health-related quality of life. Annoyance and sleep disturbance mediated the effects of NS on health. Schreckenberg et al. (2010) conclude that NS people were more critical of their environmental quality, in particular with regard to air traffic. This phenomenon was earlier referred to by Weinstein as “critical tendency” (1980). Fyhri & Klaeboe (2009) concluded that only NS was related to hypertension and chest pain, while no relationships between noise exposure and health complaints were identified. It is concluded that it is conceivable that individual vulnerability is reflected both in ill health and NS. Heinonen et al. (2007) found that cardiovascular mortality was significantly increased only in NS women. Based on this it was concluded that NS may be a risk factor for cardiovascular mortality in women, which is a slightly different interpretation than that suggested by Fyhri & Klaeboe (2006). No main effect of NS was observed by Ljungberg & Neely (2007) in cognitive aftereffects of vibration and noise exposure.

Ryu & Jeon (2011) found NS to have a greater influence on the percentage of highly annoyed by indoor noise than outdoor noise. Marks & Griefahn (2007) report a high correlation between noise sensitivity and subjective sleep quality in terms of decreased restoration and calmness, difficulty to fall asleep, and body movements. The results suggest that noise induced sleep disturbance is mediated by NS.

### *Role of social economic status*

Very few studies addressed the role of social economic factors. Theoretically, this relation would operate via learned helplessness (Evans 2006) and unequal distributions of noise. Low SES groups/areas might be more at risk due to accumulations of exposures at residential level (noise, airpullution etc) and of residential and work exposures. In the USA and UK an association was previously found between income level and exposure levels (Evans et al. 2002). In the NL no such SES differences were confirmed, except for rail noise. Both at higher and lower ends of the gradient more noise exposure were found (Kruize 2007). Likewise Fyhri & Klaeboe (2006) did not find a SES related noise distribution in Oslo, but they did find an income mediated association in a medium size city.

## CONCLUSIONS

Vulnerable groups regarding environmental noise have been understudied, are generally underrepresented in study populations, and evidence is still highly anecdotal. Effects of noise in schoolchildren are the best documented. The available evidence shows that children are less vulnerable for annoyance than adults, but more vulnerable for cognitive effects of noise. They are not per se more vulnerable as a group, but more at risk because of less developed coping strategies and they are in a sensitive developmental period. This is indicative of a life phase effect rather than an age effect. Children seem to be less vulnerable for awakenings due to noise but more vulnerable for physiological effects during sleep and related motility. There is some evidence that annoyance from both road- and air traffic noise predict asthma prevalence in children (both self reported and diagnosed). Evidence does not indicate that the elderly are more vulnerable to noise in terms of annoyance and sleep disturbance. Age specific comparisons rather show a U shaped relation and indicate that both young and older people are less at risk as far as annoyance and disturbance are concerned. But possibly the elderly are more vulnerable regarding CVD effects and this may be a combined effect of air pollution and noise. The role of noise annoyance and noise sensitivity in this relation is still inconclusive. Noise sensitivity related effects might be part of a more generic vulnerability effect, which could be psychologically and/or physiologically based. Gender differences in terms of vulnerability for CVD effects should also be further studied. A further distinction between susceptible people, places and periods might be useful for future research. More attention for specific groups at risk is warranted, such as the mentally ill, shift-workers, people suffering from tinnitus. Also the distribution of noise over SES groups deserves more attention, as well as the accumulation of exposures (noise & air), the accumulation of residential and work related exposures and places with less opportunity for recovery from daily stressors (lack of restoration). It may also be fruitful to study differential effects of noise from a more contextual viewpoint and take life course and life phase related aspects into account. This includes looking at studies into the health effects of noise in groups based on e.g. social economic status, working situations and places as well as looking at specific susceptibility for noise during the life stages and an accumulation of risk during the life course. To further this field it is necessary in future studies to present and compare subgroup-specific exposure effect relations. Generic use of the term “vulnerable groups” should be avoided since the mechanisms are quite different and maybe more important: they vary in time, place and across contexts. Groups at risk or susceptible groups, periods or places would in most case be more appropriate terms to use.

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# Dose-response relationships between hypertension and several night noise indices of aircraft noise exposure around the Kadena US airfield in Okinawa

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## INTRODUCTION

There are a few evidences reported that cardiovascular effects of traffic noise are related to a kind of night noise index (Babisch 2011). Although WHO-EU released a night noise guideline in 2009 (WHO 2009) using $L_{night}$ as the noise index, the causation between the health effects and noise exposure is explained based on indirect relationships among health effects, sleep disturbances and noise exposure. And the index $L_{night}$ is employed as the night noise index in the guideline for mainly practical reasons. However, our study of awakening process based on the neuro-physiological model (Tagusari et al. 2009) suggests that evaluation of night noise exposure by means of $L_{night}$ where sound power is averaged on power basis seems to be inappropriate because it is not sound power the brainstem integrates but awakening potential. Moreover, it would be more understandable if the frequency of sleep disturbances is more related with health effects than the integrated sound power is. This paper reports dose-response relationships between hypertension and noise indices based on the results of the Okinawa study conducted in 1995–1998 around the Kadena and the Futenma US airfields (Okinawa Prefectural Government 1999; Matsui et al. 2004, 2008). To find an appropriate noise index for the evaluation of the risk of hypertension, several noise indices were examined in the analysis. The average number of awakenings per year was applied as an index as well as the conventional noise indices such as $L_{den}$, $L_{day}$, $L_{night}$ and the number of night noise events per year. The dose-response relationships were obtained around the Kadena and the Futenma airfields respectively to investigate the validity of the noise indices.

## METHOD

### Material

Systolic and diastolic blood pressures were obtained from the records of the health examination conducted by the local governments around the Kadena and the Futenma airfields in Okinawa, Japan (see Figure 1) in the fiscal years of 1994 and 1995. The examination covered the residents who were self-employed persons, part-time workers, house wives and unemployed persons, and contained the information about age, gender, weight, height and home address. Table 1 shows the valid sample size of the above examination in each municipality for different classes of $L_{den}$ which is calculated on the basis of the measurement conducted by DFAA (Defence Facilities Administration Agency) in 1977.

Our previous papers (Matsui et al. 2004, 2008) employed the above $L_{den}$ (see Figure 1) to determine dose-response relationships between hypertension and noise exposure. In this paper, the validity of the several noise indices were examined on the basis of the recent measurement conducted by the Okinawa Prefectural Government in 1997 and 1998.

Noise indices of $L_{den}$, $L_{day}$, $L_{night}$, the number of night noise events, the outdoor level of which exceeded 70 dB ($N_{night,70\ dB}$) and the estimated average number of awakenings per year ($N_{awake}$) (ANSI 2008) were calculated from the one-year measurements at the 19 monitoring points as shown as K1 to K11 and F1 to F8 in Figure 1. In the calculation of $N_{awake}$, the residential sound insulation was assumed as 20 dB. Table 2 shows the calculated noise indices at the monitoring points and the classes of $L_{den}$ as presented in Figure 1 which are based on the DFAA's measurement in 1977.

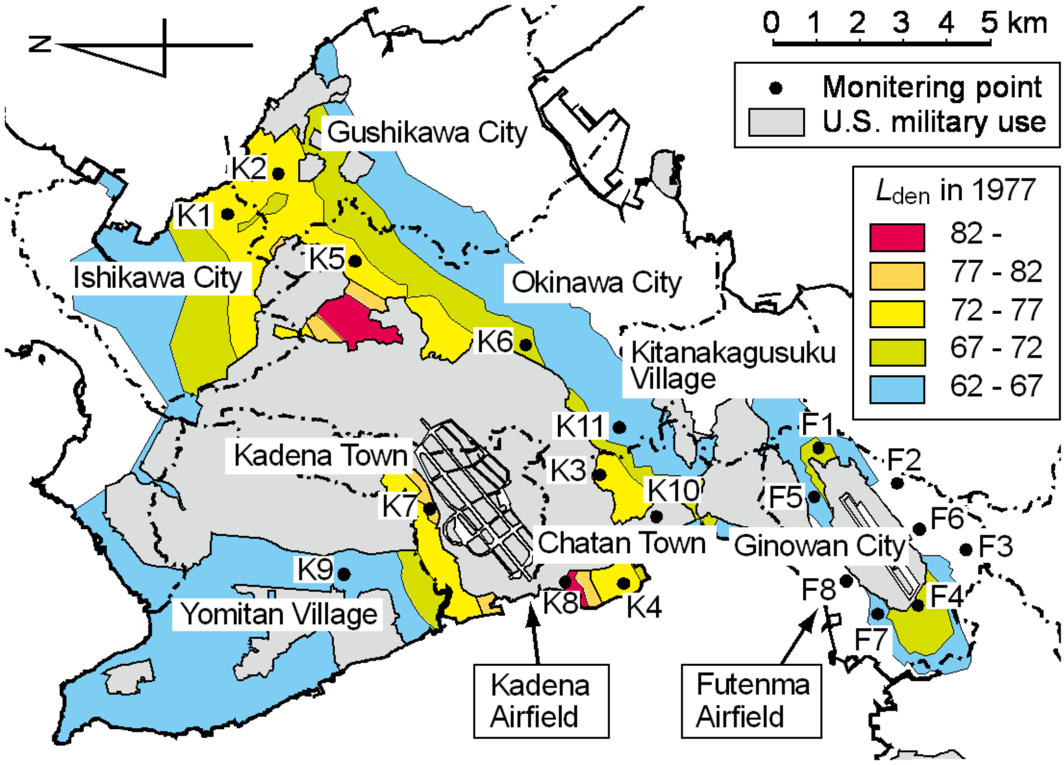


**Figure 1:** Noise monitoring points around Kadena and Futenma airfields (K1–K11 and F1–F8).

**Table 1:** Sample size in the municipalities stratified by $L_{den}$ measured in 1977

| Year | Municipality | $L_{den}$ in 1977 (dB) | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | | –62 | 62–67 | 67–72 | 72–77 | 82–87 | 87– | |
| 1994 | Okinawa City | 2,938 | 4,337 | 1,006 | 189 | 0 | 0 | 8,470 |
| | Kadena Town | 0 | 0 | 0 | 1,556 | 155 | 0 | 1,711 |
| | Chatan Town | 0 | 441 | 923 | 437 | 15 | 93 | 1,909 |
| | Kitanakagusuku Village | 1,190 | 2 | 0 | 0 | 0 | 0 | 1,192 |
| 1995 | Ishikawa City | 338 | 905 | 642 | 101 | | | 1,986 |
| | Gushikawa City | 2,066 | 1,627 | 247 | 213 | | | 4,153 |
| | Ginowan City | 2,140 | 1,750 | 1,061 | | | | 4,951 |
| | Okinawa City | 80 | 85 | 1 | 0 | | | 166 |
| | Yomitan Village | 0 | 4,021 | 222 | 0 | | | 4,243 |
| Total | | 8,752 | 13,168 | 4,102 | 2,496 | 170 | 93 | 28,781 |

**Table 2:** Noise indices calculated from the measurements in 1997–1998 for one year

| ID | Monitoring Point | Measured days | $L_{den}$ in 1977 (dB) | $L_{den}$ (dB) | $L_{day}$ (dB) | $L_{night}$ (dB) | $N_{night,70dB}$ (/year) | $N_{awake}$ (/year) |
|---|---|---|---|---|---|---|---|---|
| K1 | Mihara | 365 | 72–77 | 67.9 | 67.4 | 57.6 | 687 | 41.7 |
| K2 | Konbu | 363 | 72–77 | 64.0 | 64.0 | 52.5 | 518 | 30.0 |
| K3 | Kamisei | 364 | 72–77 | 59.4 | 60.0 | 47.2 | 414 | 27.2 |
| K4 | Miyagi | 364 | 72–77 | 61.5 | 62.4 | 48.4 | 361 | 18.8 |
| K5 | Kitami | 357 | 72–77 | 60.1 | 60.5 | 47.8 | 414 | 19.3 |
| K6 | Yaejima | 359 | 67–72 | 52.3 | 53.4 | 38.6 | 72 | 2.4 |
| K7 | Yara | 365 | 77–82 | 64.3 | 64.5 | 52.9 | 1,022 | 52.9 |
| K8 | Sunabe | 350 | 82–87 | 75.7 | 76.0 | 64.2 | 806 | 73.1 |
| K9 | Iramina | 186 | 62–67 | 53.5 | 49.8 | 46.3 | 96 | 8.2 |
| K10 | Kuwae | 82 | 72–77 | 53.9 | 55.7 | 19.9 | 4 | 0.4 |
| K11 | Yamauchi | 68 | 62–67 | 51.1 | 52.8 | 30.3 | 27 | 2.1 |
| F1 | Nodake | 363 | 67–72 | 61.6 | 62.3 | 47.3 | 157 | 4.3 |
| F2 | Aichi | 365 | 57–62 | 53.0 | 52.9 | 37.4 | 59 | 2.5 |
| F3 | Ganeko | 361 | 57–62 | 49.7 | 50.4 | 33.7 | 49 | 2.4 |
| F4 | Ueohjana | 290 | 67–72 | 67.1 | 67.7 | 48.6 | 94 | 3.7 |
| F5 | Sinjo | 365 | 62–67 | 59.5 | 60.4 | 44.2 | 283 | 10.0 |
| F6 | Ginowan | 365 | 57–62 | 54.7 | 54.8 | 39.2 | 89 | 3.5 |
| F7 | Mashiki | 365 | 62–67 | 55.7 | 57.1 | 37.8 | 92 | 4.9 |
| F8 | Ohyama | 82 | 57–62 | 50.8 | 52.5 | 28.8 | 4 | 0.1 |

It should be noted that there exists unavoidable margin of error in the estimation of noise exposure of individual subjects due to the insufficient number of monitoring points. The noise indices and their contours were estimated in each municipality on the basis of the noise indices at the monitoring points (Table 2) and the noise contour of $L_{den}$ shown in Figure 1.

## Statistical procedures

Firstly, correlations between the noise indices at the monitoring points were examined to check whether there is marked discrepancy between the indices. If the noise indices have strong correlation, it is difficult to find the difference of the dose-response relationships between the noise indices.

Secondly, multiple logistic regression analysis was applied to determine the dose-response relationship between aircraft noise level and the risk of hypertension defined by WHO with adjustment for gender, age (20–79 years with 6 categories) and BMI (5 categories).

In the analysis, the dose-response relationships around the Kadena and the Futenma airfields were determined respectively to verify the validity of the noise indices. Trend analysis was also applied to investigate the statistical significance of linear dose-response relationship with the noise index. All the statistical analyses were done with SPSS 15.0J.

RESULTS

Figure 2 shows the correlations between the average number of awakenings per year and night noise indices. The average number of awakenings ($N_{awake}$) has higher correlation with the number of noise events exceeding 70 dB ($N_{night,70\ dB}$) than with $L_{night}$ around the Kadena and the Futenma airfields. This result suggests that the difference between $N_{awake}$ and $N_{night,70\ dB}$ may not be clearly found in the evaluation of noise effects by means of the logistic regression analysis.

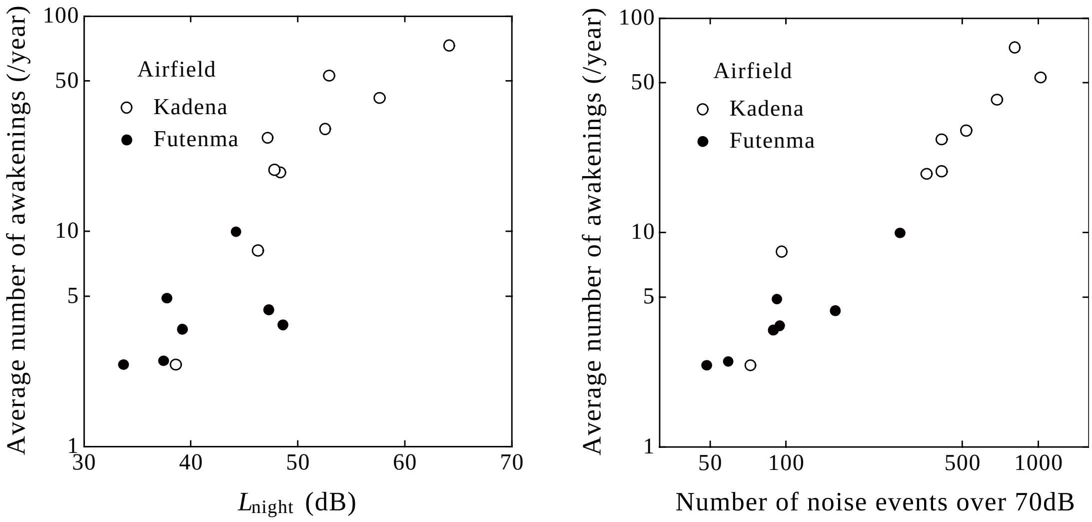


**Figure 2:** Correlation between the average number of awakenings and night noise indices. The average number of awakenings has higher correlation with the number of noise events over 70 dB than with $L_{night}$ around Kadena and Futenma airfields.

The dose-response relationships between the risk of hypertension (grade 2) and the noise indices were illustrated in Figures 3–5. In Figure 3, the significance of the dose-response relationship around the Kadena airfield determine from the measurements in 1997–1998 is substantially higher ($p=0.530\times10^{-6}$) than that of 1977 ($p=0.239\times10^{-3}$). The odds ratio in the highest noise-exposed group obtained from the recent measurements was higher than that from the old noise measurements. There are remarkable differences between the results of the Kadena and the Futenma airfields, which suggest that $L_{den}$ may not be an appropriate index to evaluate the risk of hypertension.

Figure 4 shows the differences between the indices $L_{day}$ and $L_{night}$. The index $L_{day}$ does not make any significant trend with respect to the risk of hypertension. Clear significant dose-response relationship can be found with the index $L_{night}$ around the Kadena airfield, whereas no increasing trend is found around the Futenma airfield. Around the Kadena airfield, highly significant linear increase of the odds ratio was observed from 40 dB and above in $L_{night}$. These results suggest that noise exposure during night would be an important factor causing hypertension, and that the index $L_{night}$ is not necessarily a useful index for the evaluation of the risk of hypertension due to noise exposure around the airfields.

Highly significant dose-response relationships are found with hypertension and both the average number of awakening and the number of night noise events over 70 dB around the Kadena airfield as are shown in Figure 5. Moreover, these indices did not demonstrate any increase of the risk of hypertension around the Futenma airfield where relatively small number of awakenings/events was measured. These results indicate the advantage of the indices, $N_{awake}$ and $N_{night,70\ dB}$, than $L_{night}$ for the evaluation of the risk of hypertension due to the aircraft noise exposure.

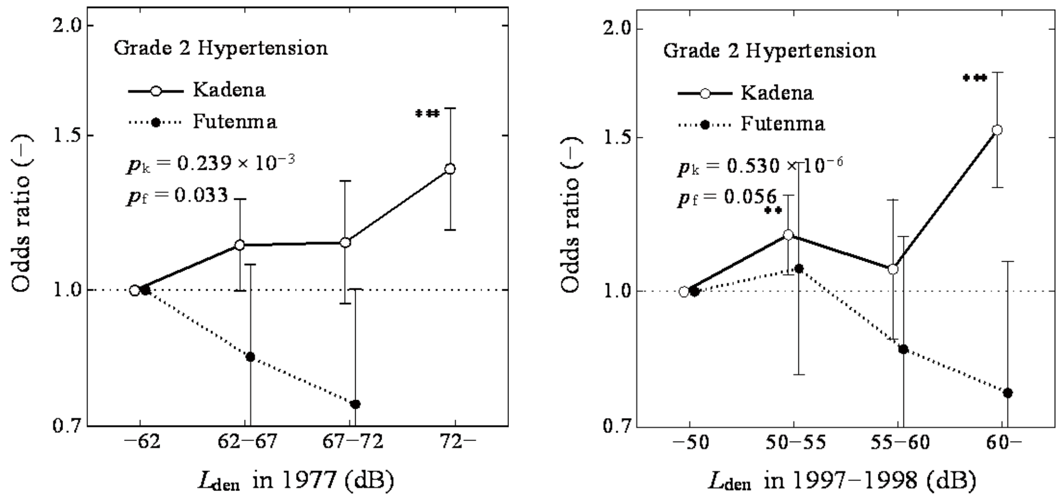


**Figure 3:** Comparison of the dose-response relationships between the risk of hypertension and $L_{den}$. The left and the right figures were based on the measurements in 1977 and in 1997–1998 respectively.

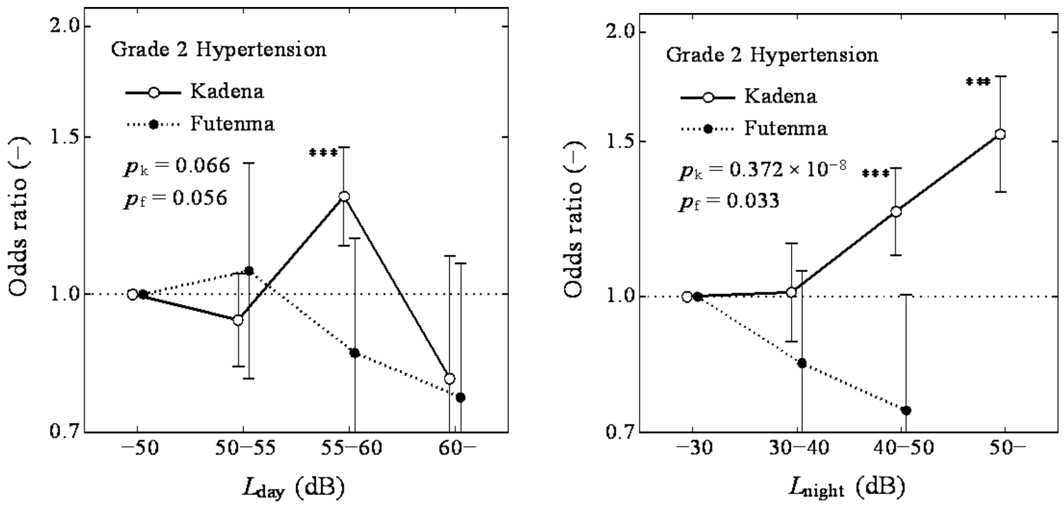


**Figure 4:** Comparison of the dose-response relationships with $L_{day}$ and $L_{night}$.

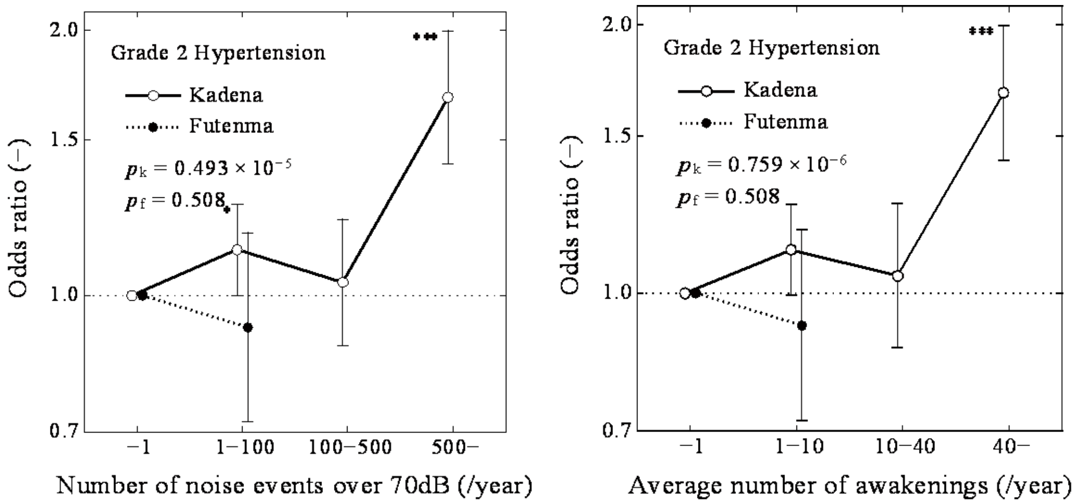


**Figure 5:** Comparison of the dose-response relationships with the average number of awakenings and the number of night noise events over 70 dB

In this study, the difference between $N_{awake}$ and $N_{night,70\ dB}$ was not detected, since they have a strong correlation (see Figure 2). The index $N_{night,70\ dB}$, however, has a shortcoming to evaluate noise effects in the sense that it does not utilize available information of sound level which is closely related with the probability of awakenings. Table 3 shows the odds ratios of hypertension together with their confidence intervals around the Kadena airfield for $L_{night}$ and the average number of awakenings per year ($N_{awake}$).

**Table 3:** Odds ratios with 95% confidence intervals vs. night noise indices

| $L_{night}$ (dB) | –30 | 30–40 | 40–50 | 50– |
|---|---|---|---|---|
| Odds ratio (95% CI) | 1.00 | 1.01 (0.89–1.15) | 1.25 (1.12–1.40) | 1.53 (1.32–1.78) |
| Number of subjects | 10,285 | 4,462 | 5,758 | 2,133 |
| $N_{awake}$ (/year) | 0–1 | 1–10 | 10–40 | 40– |
| Odds ratio (95% CI) | 1.00 | 1.12 (0.99–1.26) | 1.05 (0.87–1.26) | 1.68 (1.41–2.00) |
| Number of subjects | 5,422 | 13,346 | 2,051 | 1,819 |

## DISCUSSIONS

Applying a neuro-physiological model (Phillips & Robinson 2007, 2008), the authors analysed the neuro-electrical thresholds of awakenings, and obtained the following results (Tagusari et al. 2009);

- The brainstem does not integrate the sound energy of external stimuli but integrates awakening potential of external stimuli.
- The brainstem integrates the potential with a lag system of first-order and a time constant of approximately 10 to 100 seconds.
- The threshold levels of awakening due to short-duration noises are extremely high and $L_{max}$ and SEL both give over-estimates.
- The index SEL gives over-estimates even for long duration noises, because the brainstem integrates the awakening potential with a time constant of 10 to 100 seconds.

These findings suggest that $L_{night}$ gives over/under estimates in the evaluation of awakening response. The authors developed a new night noise index based on the findings which is calculated by integrating the awakening potential and is applicable to road traffic noise as well as aircraft noise (Matsui et al. 2010).

Comparison of the results with regard to $L_{night}$ and the average number of awakenings (see Figure 4 and 5) strongly suggests that the number of awakenings has more definite efficiency in the evaluation of the risk of hypertension than $L_{night}$ has. The index $N_{awake}$ shows good consistency between the Kadena and the Futenma airfields.

Recent experimental studies revealed that the effect of sleep depth causes many physiological changes in the endocrine system (Tasali et al. 2008; Ogawa et al. 2009). Behavioral awakening is the final response of sleep disturbance. An index related with the change of sleep dept $L_{night}$ might be better index to evaluate the risk of hypertension and other non-auditory effects of noise than the index of behavioural awakenings.

Figure 8 shows the number of awakenings at the 9 monitoring points around the Kadena airfield calculated on the basis of the method proposed by Anderson & Miller (2007). The monitoring points, K8, K7 and K1, are classified into the highest noise exposed group in Figure 5 and Table 3. At these points, more than 25 % of the residents could be diagnosed as “an environmental sleep disorder.” The percentage of the subjects diagnosed as an environmental sleep disorder (2 or 3 times awake a week) could evaluate the risk of hypertension better than the average number of awakenings.

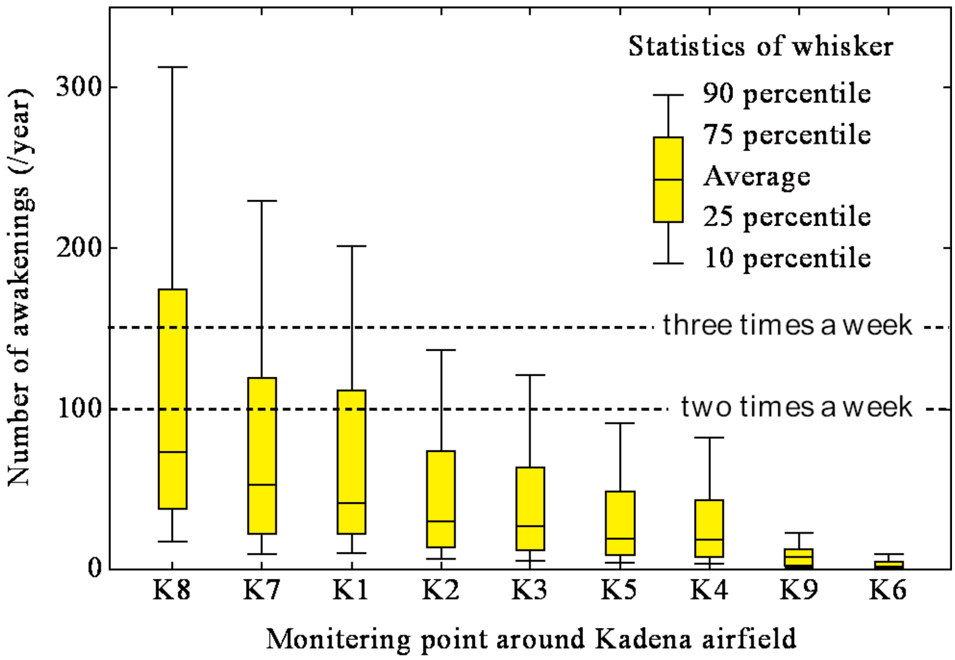


**Figure 8:** Individual differences of the number of awakenings around Kadena airfield estimated from the records at the noise monitoring points based on the existing equation (Anderson & Miller 2007). Around the monitoring points K8, K7 and K1, significant increase of hypertension was observed from the multiple logistic regression analysis. The individuals having over 100 or 150 awakenings per year would be diagnosed as “an environmental sleep disorder.”

## CONCLUSION

This paper examined the validity of several noise indices including $L_{night}$ and the average number of awakenings using the data from the Okinawa study conducted around the Kadena and the Futenma airfields in 1995 to 1998. Multivariate analysis indicated that the index of the average number of awakenings per year gives better consistency to evaluate the risk of hypertension than $L_{night}$. $L_{night}$ showed significant dose-response relationship around the Kadena airfield, but did not show similar results around the Futenma airfield.

The neuro-physiological mechanism of awakening (Tagusari et al. 2009) suggests that sound energy based indices like $L_{night}$ are not unsuitable to evaluate noise effects on sleep. The finding is also supported by the obtained results in this paper. If the noise is measured as a set of single noise events, the number of awakenings is calculated as a summation of the awakening probability of each noise event using an existing dose-response relationship on awakenings. However, the existing relationships cannot be applied to more or less continuous noise like road traffic noise. The authors have developed a night noise index indicating the number of awakenings based on the awakening potential (Matsui et al. 2010). The index is applicable to both single and continuous noise, although further studies are required to determine the stable relationship between the awakening potential and sound level.

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The authors wish to express their gratitude to Okinawa Prefecture government for its support to carry out the study.

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# The quantitative relationship between road traffic noise and hypertension: a meta-analysis

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## INTRODUCTION

Several reviews from World Health Organization (WHO) and the Health Council of the Netherlands (HCN) (WHO 1999, 2009; Health Council of the Netherlands 1994, 2004) have suggested that road traffic noise is associated with high blood pressure changes, high blood pressure and cardiovascular disease. The biological plausibility of the hypothesis of the effects of noise on the cardiovascular system is substantial and assumes that noise acts as a stressor and as such has the potential of directly and indirectly precipitating diseases (WHO 1999). The conclusions of the WHO and the Health Council of the Netherlands were partly confirmed by recent meta-analyses, showing that the results of studies investigating the associations between road- and aircraft noise exposure and cardiovascular disease converged (van Kempen et al. 2002; Babisch 2008; Babisch & van Kamp 2009). Data-aggregation produced exposure-effect relations which are suggested as a tool for quantitative health impact assessment and (noise) burden of disease calculation (WHO 2011; Berry & Flindell 2009; European Environment Agency 2010).

Despite the fact that during the last decade the number of studies investigating the association between road traffic noise and high blood pressure increased substantially, no reliable exposure-response relationship is as yet available. One of the reasons might be due to the fact that the findings of observational studies are often distorted by different sources of bias causing a fair amount of heterogeneous variation on study level. In order to derive a quantitative exposure response relationship for the association between road traffic noise exposure and hypertension and to gain more insight into the sources of heterogeneity among study results, a meta-analysis was carried out. A meta-analysis or quantitative overview is a systematic review that employs statistical methods to combine and summarise data from several studies (Teagarden 1989).

## METHODS

We identified observational studies examining the association between road traffic noise exposure and hypertension published between 1970 and 2010 in English, German or Dutch from earlier systematic reviews (van Kempen et al. 2002; Babisch 2006). In addition, we performed a short electronic search in PubMed with the following search criteria: terms for both hypertension ("hypertension", "high blood pressure") and road traffic noise in the title, sub-heading or abstract. Furthermore, we manually scanned reports and proceedings in the area of noise and health.

Subsequently, we evaluated the identified studies on their suitability for data extraction. We included studies that met the following criteria for data extraction: (i) title and/or abstract of the given study had to involve road traffic noise exposure in relation to hypertension and/or use of antihypertensives. This meant that in the given studies, the relation between road traffic noise exposure and hypertension had to be studied in a study population of healthy adults; and (ii) the study had to quantify and/or describe the relation between road traffic noise exposure - expressed in dB(A) - and hypertension due to road traffic noise. With regard to the exposure-response relation, an equation that described the association between the percentage of hypertensive people and road traffic noise had to be reported, or the percentage hypertensive people had to be reported for several exposure levels/groups. 27 of the 31 studies met the above-mentioned selection-criteria and were selected for data-extraction. In order to make a comparison between the selected studies, we extracted one or more estimates of the natural logarithm of the OR and its variance per 5 dB(A). For data-aggregation we only included estimates from studies that were well-matched or adjusted for age and gender. A pooled OR per 5 dB(A) was calculated using SAS Proc Mixed software to fit a random-effect model (van Houwelingen et al. 2002).

## RESULTS AND DISCUSSION

Table 1 shows some characteristics of the 27 cross-sectional studies that were included into the data-extraction (references shown in Table 1). Of the studies 17 are from Central Europe, six from Northern Europe, three from Southern Europe and one from Japan. Of the 27 studies, nine were published before 2000. Sample sizes ranged from 357 to 38,849 persons. The studies were carried out among equivalent sound levels ($L_{Aeq,\ 16hrs}$) in the range of 30 – 80 dBA. The results of a meta-regression analysis, including analyses of heterogeneity, have been submitted to a peer-reviewed journal and will be shown at the ICBEN conference.

At the moment, environmental health risk assessment is increasingly being used in the development of noise policies, public health decision making, the establishment of environmental regulations and the planning of research. This not only involves the identification of environmental hazards, but also the quantification of the expected health burden: health impact assessment (WHO 2000). After selecting a set of end-points for which there is sufficient evidence for an association with noise exposure, the expected health burden due to noise exposure in a specific population can be quantified by combining data on population density with exposure distributions on noise (exposure assessment) and information on exposure-effect-relationships. A clear example of the increased use of environmental health risk assessment in the area of noise, can be demonstrated with the European Noise Directive (Directive 2002/49/EC, 2002): In the framework of this directive, agglomerations and administrators of infrastructures within the member states were mandated to create noise maps and to report the total number of people exposed to noise levels of 55 dB $L_{den}$ and more, the number of people exposed to noise levels of 50 dB $_{Lnight}$ and more, and the number of noise-sensitive buildings and areas. In addition, the number of people annoyed and sleep-disturbed had to be reported as well. Since there is sufficient evidence that environmental noise from transportation increases the cardiovascular risk, and because exposure-response relationships regarding the relationships between road traffic noise and myocardial infarction (Babisch 2008) as well as the relationship between aircraft noise and hypertension (Babisch & van Kamp 2009) have been derived, the number of people with cardiovascular disease due to noise exposure could also be reported. In fact, these relationships are currently being used for quantitative impact assessment of transportation noise on cardiovascular health (European Environment Agency 2010; Hänninen & Knoll 2011). The outcome of our meta-analysis and the exposure-response relationship of the association between road traffic noise and hypertension, will complete the current knowledge about quantitative relationships between environmental transportation noise and cardiovascular health.

## CONCLUSION

Overall evidence shows that road traffic exposure is associated with high blood pressure. Based on a meta-analysis a quantitative relationship is derived that can be used for health impact assessment. The results of this meta-analysis are consistent with a slight increase of cardiovascular disease risk in populations exposed to transportation noise.

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**Table 1:** Characteristics of the studies that were included into the data-extraction (N=27)

| City or study acronym | First author | Country | Period | Population | | Exposure | | Adjust-ment* |
|---|---|---|---|---|---|---|---|---|
| | | | | Gender†, age [yrs] | N‡ | Assess-ment $ | Range (in $L_{Aeq16hrs}$) [37] | |
| Doetinchem | Knipschild 1979 | Netherlands | 1973-74 | F, 40-49 | 1,741 | 3 | 55-60, 65-70 | A, G, O |
| Amsterdam | Knipschild 1984 | Netherlands | 1977-80 | M, F, 41-43 | 2,878 | 2 | <55, 55-59, 60-64, 65-69, 70-80 | A, G |
| Erfurt | Wölke 1990 | Germany | 1976-80 | M, F, all ages | 357 | 2 | 58, 73 | G |
| Bonn | Von Eiff 1980 | Germany | 1978-79 | M, F, 20-59 | 931 | 1 | ≤50-55, 66-73 | A, G |
| Caerphilly | Babisch 1988 | United Kingdom | 1981-83 | M, 45-59 | 2,512 | 2 | 51-55, 56-60, 61-65, 66-70 | G |
| Luebeck | Herbold 1989; Hense 1989 | Germany | 1984 | M, F, 30-69 | 2,295 | 2 | ≤60, 61-65, >65 | A, G, B, S, O |
| Berlin | Babisch 1994; Wiens 1995 | Germany | 1989-90 | M, 31-70 | 2,169 | 1 | ≤60, 61-65, 66-70, 71-75, 76-80 | A, G, S |
| TRANSIT | Babisch 2006 | Austria | 1989-91 | M, F, 25-64 | 1,989 | 3 | <45 - ≥70 | A, G, S |
| SHEEP | Selander 2009 | Sweden | 1992-94 | M, F, 45-70 | 2,095 | 1 | <50, ≥50 | A, G, O |
| Tokyo | Yoshida 1997 | Japan | 1996-97 | F, 20-60 | 366 | 1 | 45-59, 50-54, 55-59, 60-64, 65-69, 70-75 | A, G |
| Stockholm | Bluhm 2007 | Sweden | 1997 | M, F, 18-90 | 667 | 3 | ≤45, 45-50, 50-55, 55-60, 60-65, >65 | A, B, S, O |
| Groningen | De Kluizenaar 2007 | Netherlands | 1997-98 | M, F, 28-75 | 38,849 | 1 | 45-65 | A, G, S, O |
| PREVEND | De Kluizenaar 2007 | Netherlands | 1997-98 | M, F, 28-75 | 7,264 | 1 | 45-65 | A, G, S, O |
| UIT1 | Lercher 2000; Lercher 2008 | Austria | 1998 | M, F, 18-74 | 1,503 | 3 | 50-60 | A, G, S |
| Spandau | Maschke 2003 | Germany | 1998-99 | M, F, 18-90 | 1,718 | 1 | <55, 55-60, 61-65, >65 | A, G, B, S, O |
| Skane-1 | Björk 2006 | Sweden | 1999-00 | M, F, 18-80 | 13,557 | 1 | <50, 50-54, ≥55 | A, G, B, S, O |
| Lerum | Barregard 2009 | Sweden | 2004 | M, F, 18-75 | 1,953 | 1 | 45-50, 51-55, 56-70 | A, G, B, O |
| Skane-2 | Bodin 2009 | Sweden | 2004 | M, F, 18-80 | 24,238 | 1 | 45-71 | A, G, B, S, O |
| EHIA_BBT (phone) | Lercher 2008; Heimann 2007 | Austria | 2004 | M, F, 20-74 | 2,007 | 3 | 30 – 80 | A, G, B, S |
| EHIA_BBT (face to face) | Lercher 2008; Heimann 2007 | Austria | 2004 | M, F, 17-85 | 2,070 | 3 | 30 – 80 | A, G, B, S |
| Belgrade | Belojevic 2008 | Serbia | 2004 | M, F, 18-96 | 2,503 | 2 | Approx. ≤55, >55 | A, G, B, O |
| HYENA | Jarup 2008 | United Kingdom, Netherlands, Sweden, Italy, Greece, Germany | 2005-06 | M, F, 45-70 | 4,861 | 1 | 45-70 | A, G, B, S, O |

†) M = Males; F = Females. ‡) Number of subjects. $) 1 = modelled; 2 = measured; 3 = both; *) A = age, G = Gender, B = relative body weight; S = Socio-economic status; O = Others

# Traffic noise and blood pressure in North-American urban schoolchildren

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## INTRODUCTION

The association between community noise and hypertension in adults has been investigated in numerous, predominantly European studies with suggestive evidence for a causal relationship (Stansfeld & Crombie 2011; Kempen 2011; Belojevic et al. 2011; Bluhm & Eriksson 2011; Masche 2011). However, there have been relatively few studies on noise and blood pressure in children with many showing weak overall effects, indicating the importance of factors related to noise exposure, study design, sample characteristics and procedure of blood pressure measurement (Evans 2006; Paunovic et al. 2011). Nevertheless, investigations of environmental factors that may influence blood pressure regulation in children are needed because elevated blood pressure in childhood (Sun et al. 2007) and adolescence (Vos et al. 2003) are likely track on into adulthood.

Since the studies of Cohen et al. (1980, 1981) researches on community noise and blood pressure in children in the USA are lacking. A specific feature of North-American children is ethnic diversity and this potential noise effect modifier has rarely been studied in children (van Kempen et al. 2006).

The aim of this study in the city of Syracuse was to investigate the relationship of exposure to noise at home and at schools and children's blood pressure. We focused on three possible effect modifiers: orientation of living room and bedroom, ethnicity and age.

## METHODS

### Study sample

Children were recruited from four Boys and Girls Clubs in Syracuse, USA Boys and Girls Clubs are a national organization devoted to youth development with a focus on low-income children. There were about 300 children attending these clubs permanently or occasionaly after regular school. Parents were sent letters with thorough information about the study and a permission request for including the children in the study. There were 272 positive answers (90.6 % response rate). One child with Diabetes mellitus had to be excluded from the study. The final sample consisted of 271 schoolchildren (137 boys and 134 girls) aged 6-14 years. Children were asked to sign an Assent Form. The study was approved by the Institutional Review Board of Cornell University.

### Questionnaire

Each child was interviewed prior to anthropometric and blood pressure measurement. Data were registered on gender, race, date of birth, school, period of living in the house, home floor, number of rooms, number of children and number of adults in the family, orientation of a child's bedroom and living room towards the street, mother's smoking, father's smoking, noise annoyance at home and at school in the last 12 months, using appropriate pictures (graded 0 – not at all, smiling face; 1 – some, indifferent; 2 – a lot, frowned). Data on subsidized lunch eligibility (an index of family income status) and diagnosed Diabetes Mellitus or Renal Diseases in children were obtained from the Club's administration.

### Anthropometric measurements

Body height was measured with stadiometer which had a graduation of 0.5 cm. Body weight was measured on a digital scale accurate to 0.1 kg. The children were measured in Boys and Girls Clubs, in light clothes and barefoot. Body mass index (BMI) was calculated as a quotient between body weight in kilograms and squared body height in meters. Software available on the website of the Centers for Disease Control and Prevention (http://apps.nccd.cdc.gov/dnpabmi/Calculator.aspx) was used to calculate body mass index-for-age percentile (Kuczmarski et al. 2000).

### Blood pressure measurement

A Dinamap PRO 100 oscillometric monitor (Critikon, U.S.A) was used for measurement of blood pressure, after a child's five minute rest, using an appropriate cuff on a non-dominant arm, after measuring the limb circumference (infant-8-13 cm; child-2-19 cm; small adult-17-25 cm). Calibration of the measuring system was performed according to producer's instructions. Two measurements were performed in a sitting position, with a two minute interval. If the difference between measurements exceeded 5 mm Hg, a third measurement was performed and mean values of systolic and diastolic pressures were calculated.

### Noise measurement

We used Brüel & Kjær noise level meter type 2239A. Prior to each measurement the meter was calibrated. Equivalent noise levels ($L_{eq}$) of traffic noise were measured in two 15 minute intervals in front of children's schools (between 12:00 h and 15:00 h), and in two 15 minute intervals (between 18:00 h and 22:00 h) on the streets were children lived. From the obtained $L_{eqs}$ composite $L_{eqs}$ for each address and school were calculated. Maximum noise levels at each home and school measuring sites were also registered.

### Statistical analysis

Descriptive statistic is presented as mean values ± standard deviation (SD) for numeric variables, or as percents for categorical variables. Pearson correlation analysis was performed to test the association between variables from the questionnaire and children's cardiovascular parameters. Differences between groups in parametric data were tested using Student's t-test. Mann Whitney U-test was used for nonparametric data. Multiple linear regression was performed to calculate the relation between blood pressure and relevant independent variables. A probability level of less than 0.05 was accepted as significant. SPSS 10 software was used for all data analyses.

## RESULTS

The vast majority of children in this study were African Americans (251, 92.6 %), while Non White Hispanics and Whites encompassed 4.4 % (12) and 3.0 % (8) of the sample, respectively. All the children had a subsidized lunch indicating a lower socio-economic class of their parents.

Boys and girls were comparable concerning relevant cardiovascular, acoustic and other parameters, allowing for pooling data for both sexes together in further analysis (Table 1).

**Table 1:** Relevant parameters of boys and girls from the study sample (Mean ± Standard Deviation)

| Parameter | Boys (n = 137) | Girls (n = 134) | Total (n=271) | p |
|---|---|---|---|---|
| Age (years) | 9.73±1.91 | 9.45± 1.76 | 9.59±1.83 | 0.217* |
| No. of people per room | 0.80±0.31 | 0.80±0.36 | 0.80±0.33 | 0.832* |
| Period of living on current address (years) | 2.77±2.35 | 3.05±2.56 | 2,90±2,45 | 0.352* |
| Body Mass Index for age percentile | 73.40±24.99 | 71.02±26.49 | 72.31±25.73 | 0.449* |
| Noise annoyance at home (grade) | 0.61±0.74 | 0.60±0.71 | 0.60±0.72 | 0.925# |
| Noise annoyance at school (grade) | 0.36±0.64 | 0.26±0.53 | 0.30±0.59 | 0.210# |
| Home $L_{eq}$ /dB(A)/ | 61.27±5,11 | 61.30±4,73 | 61.29±4,91 | 0.952* |
| Home $L_{max}$/dB(A)/ | 83.52±6,09 | 84.05±6,52 | 83.79±6.30 | 0.497* |
| School $L_{eq}$ /dB(A)/ | 60.92±2,52 | 61.06±2.14 | 60.99±2.33 | 0.622* |
| School $L_{max}$/dB(A)/ | 79.03±2.88 | 79.06±2.63 | 79.04±2.75 | 0.928* |
| Systolic blood pressure (mmHg) | 98.01±10.05 | 97.45±10.04 | 97.76±10,02 | 0.648* |
| Diastolic blood pressure (mmHg) | 56.01±8.64 | 55.23±7.36 | 55.62±8.01 | 0.775* |

*Student’s t-test

# Mann-Whitney U-test

Children were exposed to road-traffic noise of $L_{eq}$ ranging from 54-71 dBA at schools and 42-76 dBA at homes. Maximum noise levels in front of schools and homes ranged from 71-87 dBA and 66-95 dBA, respectively.

Correlation analysis in the overall sample showed no significant relationship between noise exposure and children’s blood pressure. Highly significant correlation was found between systolic pressure and age and BMI for age percentile, while diastolic blood pressure was strongly related only to BMI for age percentile (Table 2).

We found no interactions between noise at home and at schools as well as orientation of bedroom and/or living room and noise at home, nor was there an interaction or additive effect of noise at home and at schools on blood pressure. We also did not find any interaction of race and noise on blood pressure.

**Table 2:** Results of the Pearson correlation analysis between relevant parameters and children's blood pressure in the overall sample (n=271)

| Variable | Mean Systolic Pressure | Mean Diastolic Pressure |
|---|---|---|
| Age (years) | 0.176** | 0.053 |
| Race (African Americans and Others) | 0.121 | 0.071 |
| Apartment floor | -0.017 | -0.052 |
| No. of people per room | -0.130* | -0.047 |
| Period of living on current address (years) | -0.044 | 0.016 |
| Body Mass Index for age percentile | 0.313** | 0.172** |
| Mother smoker | 0.060 | 0.126* |
| Father smoker | 0.040 | 0.009 |
| Noise annoyance at home (grade) | -0.049 | -0.015 |
| Noise annoyance at school (grade) | -0.108 | 0.062 |
| Home $L_{eq}$ /dB(A)/ | 0.021 | -0.090 |
| Home $L_{max}$/dB(A)/ | -0.038 | -0.067 |
| School $L_{eq}$ /dB(A)/ | -0.002 | 0.035 |
| School $L_{max}$/dB(A)/ | -0.050 | -0.048 |

p<0.05 (two-tailed)
p<0.01 (two-tailed)

We formed a sub-sample of children by adding the orientation of bedroom and living room as inclusion criteria (n=137). Similar to the overall sample, there was no significant relationship between noise exposure and children's blood pressure. However, there was an interaction between noise exposure and age in the effects on systolic blood pressure. In younger children aged 6-10 years, we found a significant positive relation between noise levels at homes and systolic blood pressure, controlling for BMI for age percentile (Table 3). In older children aged 11-14 years this relation was negative and significant (Table 4).

**Table 3:** Multiple regression with systolic blood pressure as a dependent variable and body mass index for age percentile (BMI) and equivalent noise level at home /$L_{eq}$ (dBA)/ as independent variables in children aged 6-10 years (n =88)

| Variables | Unstandardized coefficients | | Standardized coefficients | t | p | 95% Confidence interval for B | |
|---|---|---|---|---|---|---|---|
| | B | Standard error | Beta | | | Lower | Upper |
| Constant | 32.723 | 15.035 | | 2.176 | 0.033 | 2.797 | 62.649 |
| BMI | 0.153 | 0.036 | 0.405 | 4.231 | < 0.001 | 0.081 | 0.224 |
| $L_{eq}$ /dB(A)/ | 0.847 | 0.239 | 0.339 | 3.544 | 0.001 | 0.371 | 1.323 |

**Table 4:** Multiple regression with systolic blood pressure as a dependent variable and body mass index for age percentile (BMI) and equivalent noise level at home /$L_{eq}$ (dBA)/ as independent variables in children aged 11-14 years (n =49)

| Variables | Unstandardized coefficients | | Standardized coefficients | t | p | 95% Confidence interval for B | |
|---|---|---|---|---|---|---|---|
| | B | Standard error | Beta | | | Lower | Upper |
| Constant | 139.678 | 18.348 | | 7.613 | < 0.001 | 102.676 | 176.681 |
| BMI | 0.123 | 0.049 | 0.349 | 2.530 | 0.015 | 0.025 | 0.221 |
| $L_{eq}$ /dB(A)/ | -0.795 | 0.302 | -0.363 | -2.634 | 0.012 | -1.403 | -0.186 |

## DISCUSSION

Our findings in the overall sample of children with no significant relationship between road-traffic noise exposure and blood pressure are congruent with the results of the studies of Evans et al. (2001) on children aged 9-10 years from Austria, and van Kempen et al. (2006) on children aged 9-10 years from the Netherlands and UK. However, in other studies significant relationship between noise from road-traffic and blood pressure was found in German children aged 8-14 years (Babisch et al. 2009) and in Serbian children aged 7-11 years (Belojevic et al. 2008; Paunovic et al. 2009). Low consistency of the results of these studies may derive from different blood pressure measurement methods (sphygmomanometer in Austrian and Serbian studies and automatic devices in Dutch, UK and German studies). Also, in some studies noise exposure was estimated in residences only (Austrian and German) and in others both in residences and schools.

Orientation of bedroom and/or living room was not an important factor in our study, although in several studies it has been denoted as an effect modifier (Babisch 2006).

We did not find an interaction of race and noise exposure in the effects on blood pressure although in the U.S.A. blood pressure category varies substantially by race/ethnicity. In adults, higher percentages of non-Hispanic blacks have hypertension compared with non-Hispanic whites and Mexican Americans (CDC 2007). In children, elevated blood pressure was most frequently found in Hispanics although ethnic differences were not significant after controlling for overweight (Sorof et al. 2004). However, the number of Non White Hispanics and Whites in our sample of children (20) was too low for reliable statistical reasoning.

The interaction of children's age and traffic noise at homes on blood pressure may be explained with more time younger children spend playing outdoors compared to adolescents (Bringolf-Isler et al. 2010).

## CONCLUSIONS

In this cross-sectional study of predominantly African American schoolchildren, the rise of systolic blood pressure was related to increased noise levels in residential areas only in younger children aged 6-10 years. There was no interaction of orientation of bedroom and/or living room and noise levels at home, race and noise, nor was there an interaction or additive effect of noise at home and at schools on blood pressure.

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# Spatial relationships between residential levels of traffic noise from road and rail and air pollution in Oslo, Norway

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## INTRODUCTION

Several epidemiological studies have reported associations between cardiovascular (CV) diseases and both traffic-related air pollution (Nafstad et al. 2004; Naess et al. 2007; Hoek et al. 2002) and road traffic noise (Babisch et al. 2005; Babisch 2006; de Kluizenaar et al. 2007; Selander et al. 2009). As both exposures have road traffic as their main source, air pollution may confound associations between road traffic noise and health outcomes, and vice versa, or these exposures may act together (Davies et al. 2009; Schwela et al. 2005).

So far, only a few studies have investigated the combined effects of both exposures, using a variety of indicators for road traffic noise, different air pollutants and CV outcomes (de Kluizenaar et al. 2007; Beelen et al. 2009; Selander et al. 2009). After adjusting for air pollution, the associations of noise with hypertension and CV mortality were marginally changed (de Kluizenaar et al. 2007; Beelen et al. 2009), except for removing the effect of noise on ischemic heart disease mortality (Beelen et al. 2009), and no strong effect modification were found with myocardial infarction (Selander et al. 2009). The reported correlations between noise and air pollution varied from weak to strong (Pearson's correlation coefficient ($r$) = 0.2-0.7). However, to our knowledge no studies have investigated the differences and similarities of the assessment approach of these pollutants in more detail, although modeled levels usually are used as exposures in epidemiological studies.

With respect to noise, it has been suggested that the levels during night-time may be most important for potential CV effects (Griefahn et al. 2008; Jarup et al. 2008). However, most epidemiological studies have only used a general noise indicator assessed at the most exposed façade (de Kluizenaar et al. 2007; Beelen et al. 2009; Selander et al. 2009), despite that many people have their bedroom facing a less exposed side of the house (Aasvang et al. 2008).

Another source of traffic is rail traffic, with a more intermittent nature than the more continuous road traffic. So far, only few recent epidemiological studies have considered health effects of rail traffic noise (Aasvang et al. 2008; Lercher et al. 2010), but no studies have reported correlations between rail traffic noise and air pollution. As potential health effects of rail traffic noise may aid in separating the effects of air pollution and traffic noise, the relationship between rail traffic noise, road traffic noise and air pollution should be evaluated.

This study is part of a large project in Oslo investigating long-term CV effects of traffic-related air pollution and noise, using modelled levels of traffic noise and of air pollution at the home address of each participant in the "The Oslo Health Study" (HUBRO). We aimed at evaluating the spatial relationships between residential indicators of traffic noise and air pollution, both at the most and the least noise exposed façade. This was performed separately for road traffic and rail traffic noise.

METHODS

### Site description

Oslo, which is the capital of Norway with about 600,000 inhabitants, is situated in a basin at the head of a 100 km long fjord, surrounded by hills up to 500 m above sea level (Oftedal et al. 2009). This topography can lead to large spatial variation in traffic-related air pollution. The average monthly temperature is –5 °C in January and 17 °C in July.

### Study addresses

The population-based HUBRO study was conducted in 2000-2001, with 45.9 (N=18,770) participation rate (Søgaard et al. 2004). Of the study participants, 17,594 accepted to link their information to registries. Using the national identification number, Statistics Norway provided the residential history with corresponding geographical coordinates for each participant. Thereby traffic noise and air pollution were linked to each subject's home address for the study participants who did not change residence during 2006 (N=16,140). Of these, 2,025 participants lived outside of Oslo in 2006, where neither noise nor air pollution was assessed. 240 participants had address more than 10 m from a building, and were not assigned to noise. Furthermore, participants assigned to background air pollution level were excluded (n=70). We included all the participants with assessed road traffic noise (levels above zero) (N=13,764), which is called the main population.

For the comparisons with rail noise we used the subpopulation with assessed rail noise levels (N=3,475). Another subpopulation was also added, including only those subjects who were assigned air pollution levels from the receptor points (N=2,632), which represents more highly exposed subjects.

### Assessment of noise

The indicators $L_{den}$ and $L_{night}$ (European Commision 2002) were calculated outside the most exposed façade and the least exposed façade of each study house in Oslo, separately for road traffic and for rail traffic noise. Noise from road traffic and rail traffic (railway, subway and tram) was calculated using the Nordic Prediction Method for road traffic noise (Nordic Council of Ministers 1996a) and for railway noise (Nordic Council of Ministers 1996b). These methods were implemented in the acoustical software program CadnaA, version 3.6 (Datakustik 2004), which used a geographic information system (GIS) to calculate the traffic noise levels on 5 x 5m$^2$ grids at 4m height (Municipality of Oslo 2007). The grid levels were interpolated at the points along the façade of each residential building, with 3 m distance between each point. All buildings and noise screens were defined as 100 % reflective and first order reflection was included in the calculations. Averages of noise measurements have shown good agreement with calculated values (Nordic Council of Ministers 1996).

Input data to CadnaA were digitalized terrain data, buildings and noise screens in 3D and ground type. Buildings were defined as building planes with maximum height of each building, and buildings demolished or built the last three years may not have been registered in the GIS. Some private noise screens were neither registered. All terrain areas were given hard ground type and completed with soft ground in areas where this was likely, such as parks, outdoor recreational areas and areas around detached houses.

Other input data to CadnaA were road traffic data (traffic counts, percentages of heavy vehicles, speed limits and diurnal distributions) from the Norwegian Public Roads Administration and the City of Oslo, and rail traffic data (frequencies, train types, train lengths and speed limits) from the National Railway Administration and from the City of Oslo (Municipality of Oslo 2007). To capture optimal quality of annual average diurnal traffic (AADT) for the road network in Oslo, all available databases of road traffic counts performed in Oslo during 2000-2006 were considered (Municipality of Oslo 2007). Only the databases with best quality of AADT were used and historical values after 2000 were interpolated to be valid for 2006, based on AADT values from 2005 for the national roads. Some of the historic traffic counts also included counts of heavy vehicles. For the rest of the road links, the City of Oslo developed a distribution of heavy vehicles based on several years of traffic counts, whereas 240 road links with a lot of bus traffic and industry were assessed separately. Diurnal distribution was based on traffic counting at 52 points on local roads in 2006, and indicates different distribution for light, medium and heavy vehicles. After evaluating whether these distributions could vary depending on road type, the same distributions may be applied on all types of local roads. For national roads, the diurnal distribution indicated 75 % road traffic in daytime, 15 % in evening and 10 % at night, which was nearly similar to the distribution used for local roads with medium traffic.

$L_{den}$ and $L_{night}$ were assessed for the residential houses within 500 m from national roads (roads with high traffic counts), houses within 300 m from local roads (roads with medium traffic counts), houses within 300 m from nearest railway and within 125 m from nearest subway or tram.

### Assessment of air pollution

The air pollution levels in Oslo in 2006 were calculated by the EPISODE model, developed by the Norwegian Institute for Air Research (Oftedal et al. 2009; Slørdal et al. 2003). The EPISODE model is a combined three-dimensional Eulerian / Lagrangian dispersion model which calculated ground level hourly average concentrations, both as grid values and at individually placed receptor points, based on emissions, meteorology and background air pollution concentrations. The Lagrangian part of the model consists of a subgrid model for calculation of concentrations from roads with AADT above 3,000 vehicles. Depending on the AADT, this sub-grid model calculated concentrations up to 500 m from the road. Beyond this zone, the Eulerian model calculated air pollution levels using 18 (N-S) and 22 (E-W) 1 x 1 $km^2$ horizontal grid cells with vertical heights at 20, 30 and 150 m from ground level and up. Concentration of each $km^2$ was calculated by combining Eulerian and sub-grid model concentrations in 100 x 100 $m^2$ sub-grids and averaging over the sub-grids within each $km^2$ grid cell. Concentration at each receptor point was determined by the sub-grid the receptor point was located within. Further details are given in Oftedal et al. (2009) and Slørdal et al. (2003). Modelling of long-term averages was recently compared with measurements in Oslo, and the EPISODE model represented long-term levels of local outdoor air pollution reasonably well (Oftedal et al. 2009).

Hourly emissions from road traffic, domestic heating, industry and other sources were input data to EPISODE. AADT for 2006 were mainly based on The National Transport Plan (2002-2011) and updates on the main road network in 1999 from Scandiaconsult. Large parts of this road network were manually checked and corrected based on traffic counts from The Norwegian Public Roads Administration for Oslo in the period 1999-2002. In addition, parts of the most important local roads were checked and updated in collaboration with the City of Oslo, and updated traffic counts on some road segments were used for 2006. The emission factors for 2001 were taken from the National Emission Model for Road Traffic, where factors for 1997 were first scaled to 2001 (Norwegian Pollution Control Authority 1999) and then further to 2005. Diurnal time variation for 2006 was based on traffic counts conducted in 2001 on the national road E18 in Drammen, a city close to Oslo, and adjusted for some night hours. The emissions were distributed by weekday and hour of the day, capturing different variation during working days and weekends.

Emissions from domestic heating and other sources such as industry, public and private service sector, motorized equipment, ship and railway traffic were provided by Statistics Norway and were primarily based on data from 1998 (Haakonsen 2000). Emissions from wood burning as a part of domestic heating were based on consumption data from 2002 (Finstad et al. 2004) adjusted to 2005 (Slørdal et al. 2007). The emissions were distributed by week, reflecting seasonal variations, and hour of the day.

The meteorological data were measured at a central meteorological station in Oslo. These variables were measured hourly: wind speed, wind direction, temperature, stability, relative humidity and precipitation. Wind and stability data were used in the wind field model MATHEW (Sherman 1978) to create hourly gridded wind fields in accordance with the local topography. Further details are given in Oftedal et al. (2009).

The hourly background concentrations of $NO_2$ were based on minimum of the 24h levels measured at the regional background station Birkenes in southern Norway. The background concentrations of ozone were based on maximum hourly values measured at two regional background stations in the south of Norway.

The air pollution indicator $NO_2$, mainly representing traffic-related air pollution, was calculated for each $km^2$ grid and at 11,452 receptor points in 2006. Assigning air pollution level, residential addresses located within 30 m from a receptor point were assigned the concentration at the nearest point, whereas other addresses were assigned the concentration of the $km^2$ grid.

### Data analysis

The residential levels of traffic noise and air pollution were presented by mean, median, standard deviation, minimum and maximum. We evaluated the spatial relationship between residential levels of traffic noise and air pollution by calculating Spearman correlation coefficient ($r_S$), separately for road and rail traffic noise. In determining annual concentrations of $NO_2$, 75 % availability was used as cut-off for a non-missing value. The spatial relationships between the two sources of traffic noise were also evaluated.

## RESULTS

Traffic noise was calculated on a finer spatial resolution than $NO_2$. All pollutants have a large spatial within-city variation.

**Table 1:** Summary statistics of road traffic noise [dB], rail traffic noise [dB] and $NO_2$ [µg/m$^3$] in 2006 in Oslo, Norway

| Pollutant | Indicator | Façade | N | Mean ± SD | Median | Min – Max |
|---|---|---|---|---|---|---|
| Road traffic noise | $L_{den}$ | Most exposed | 13,764 | 55 ± 9 | 55 | 10 – 80 |
| | | Least exposed | 13,764 | 37 ± 13 | 40 | 1 – 71 |
| | | Most exposed | *3,475 | 57 ± 8 | 57 | 22 – 78 |
| | | Least exposed | *3,475 | 39 ± 12 | 42 | 3 – 69 |
| | | Most exposed | **2,599 | 61 ± 8 | 61 | 34 – 80 |
| | $L_{night}$ | Most exposed | 13,764 | 47 ± 9 | 47 | 3 – 71 |
| | | Least exposed | 13,764 | 30 ± 11 | 32 | 1 – 63 |
| | | Most exposed | *3,475 | 49 ± 8 | 48 | 14 – 69 |
| | | Least exposed | *3,475 | 32 ± 11 | 34 | 3 – 61 |
| | | Most exposed | **2,599 | 53 ± 8 | 53 | 25 – 71 |
| Rail traffic noise | $L_{den}$ | Most exposed | *3,475 | 48 ± 11 | 48 | 12 – 73 |
| | | Least exposed | *3,475 | 33 ± 11 | 34 | 0 – 67 |
| | | Most exposed | **901 | 51 ± 11 | 51 | 23 – 73 |
| | $L_{night}$ | Most exposed | *3,475 | 40 ± 11 | 40 | 4 – 65 |
| | | Least exposed | *3,475 | 26 ± 10 | 27 | 0 – 58 |
| | | Most exposed | **901 | 43 ± 11 | 43 | 15 – 65 |
| Air pollution | $NO_2$ | NA | 13,764 | 16.1 ± 9.5 | 13.3 | 1.8 – 65.2 |
| | | NA | *3,475 | 18.3 ± 10.4 | 17.6 | 2.0 – 65.2 |
| | | Most exposed | **2,599 | 25.4 ± 9.1 | 25.0 | 3.7 – 65.2 |
| | | Most exposed | **901 | 27.3 ± 9.0 | 28.2 | 6.1 – 65.2 |

*Subpopulation with assessed rail noise levels (in addition to road traffic noise)
**N for the subpopulation including only those subjects with air pollution levels from the receptor points

The $L_{den}$ levels of road traffic noise at most exposed façade were on average 8 dB higher than $L_{night}$. The most exposed façade had on average 18 dB ($L_{den}$) and 17 dB ($L_{night}$) higher road traffic noise levels than the least exposed façade. In the subpopulation with assessed levels of rail noise all subjects also had assessed levels of road traffic noise (N= 3,475), which were on average 9 dB higher than the levels of rail noise. The $NO_2$ concentrations were higher in winter (January-April and October-December, median 15.4 µg/m$^3$) than summer (May-September, median 10.3 µg/m$^3$). In the subpopulation representing more highly exposed subjects, the traffic noise levels and the $NO_2$ levels were on average 6 dB (road traffic, $L_{den}$), 3 dB (rail traffic, $L_{den}$) and 9.3 µg/m$^3$ higher than in the main population.

Figure 1 presents the traffic noise levels for $L_{den}$ plotted versus $NO_2$, both for road traffic noise and rail noise, including the higher exposed subpopulation and Spearman correlation.

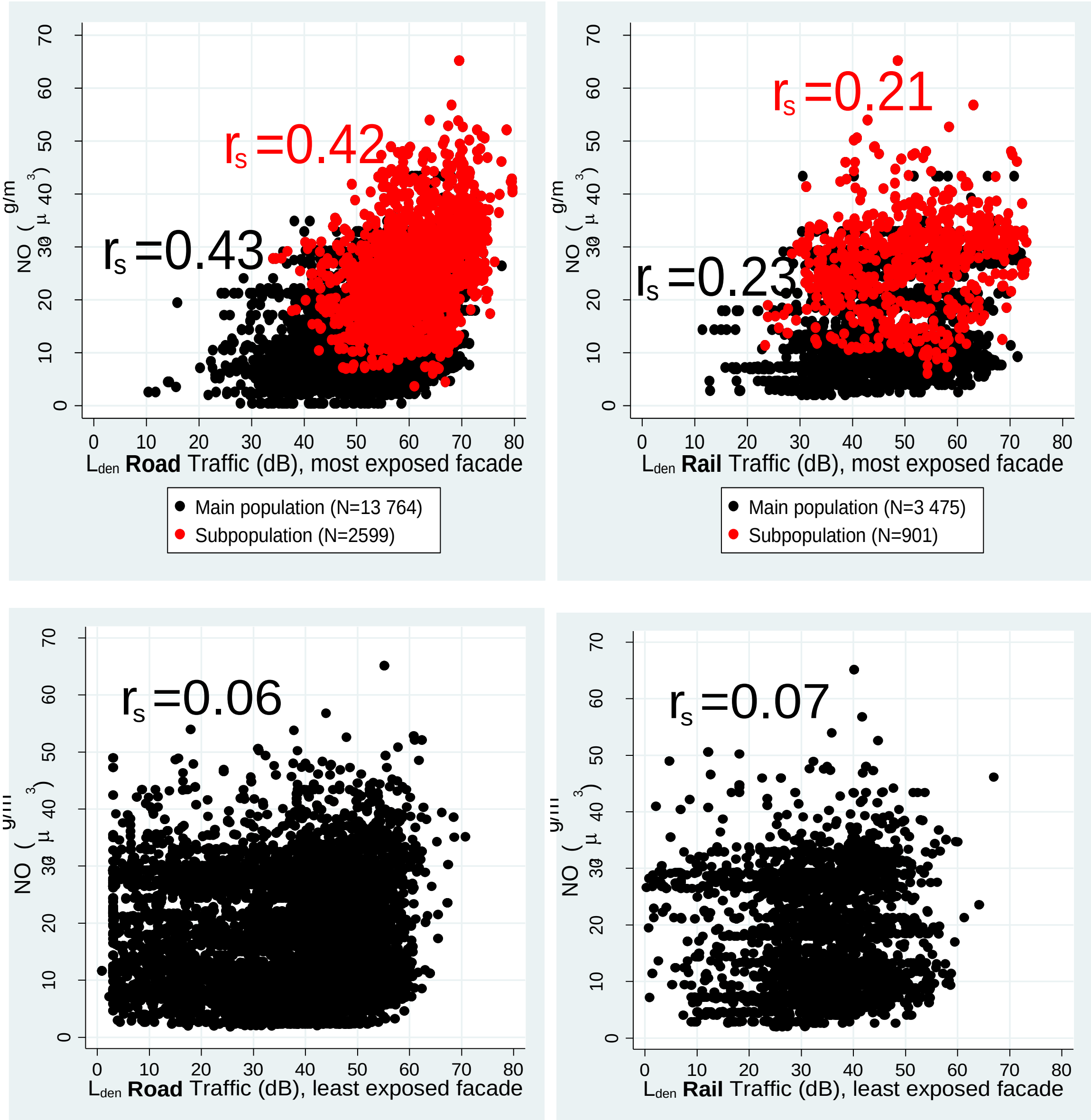


**Figure 1:** Road traffic noise at the most exposed façade and at the least exposed façade ($L_{den}$) [dB] in the first row, rail traffic noise at the most exposed façade and at the least exposed façade ($L_{den}$) [dB] in the second row, all plotted versus $NO_2$ levels [µg/m$^3$] in 2006 in Oslo, Norway.

The correlation between road traffic noise at most exposed façade and $NO_2$ was 0.42-0.43 and 0.21-0.23 between rail noise at most exposed façade and $NO_2$. The correlation between both sources of traffic noise at least noise exposed façade and $NO_2$ was lower ($r_s$=0.06-0.07). In the subpopulation with assessed rail noise levels the correlation between road traffic noise and $NO_2$ was slightly higher ($r_s$=0.48-0.49) than in the main population ($r_s$=0.42-0.43). In the subpopulation with higher exposed subjects, the correlations were unchanged (Figure 1), although slightly higher between the two sources of traffic noise ($r_s$=0.41-0.42) compared to the larger population ($r_s$=0.36-0.37). $L_{den}$ and $L_{night}$ had correlations of 1.00 when assessed at the same façade, but weaker correlations between noise at the least and the most exposed façade ($r_s$=0.26-0.28 for road traffic and $r_s$=0.60-0.62 for rail traffic noise).

## CONCLUSIONS

Both traffic-related air pollution and noise have a large spatial variation within our urban study area. Differences in applied data on road traffic, meteorology and resolutions may have contributed to slightly reduce the calculated correlation between long-term levels of road traffic noise and $NO_2$. However, we found the same correlation in the higher exposed subpopulation with finer resolution of $NO_2$, which supports our finding. Our moderate correlation suggests a potential to separate the CV effects of traffic-related air pollution and noise in Oslo. Despite the plausible weak correlation between rail noise and $NO_2$, road traffic noise dominates this population, and rail noise may not contribute additionally to disentangle effects of traffic-related air pollution and noise in our urban population. The negligible correlations at the least noise exposed façade, which is often the bedroom façade, may aid in separating effects of night-time noise from air pollution.

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# Cross-sectional association between road traffic noise and hypertension in a population-based sample in Girona, Spain (REGICOR-AIR project)

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## INTRODUCTION

Long-term exposure to traffic-related noise may increase blood pressure levels and induce hypertension, especially at night-time (WHO 2009). The evidence for the effects of road traffic noise on hypertension seems to be increasing, but some inconsistencies are still found in the size of the effects and in the effect modifiers involved in this association (such as age or gender) (e.g. de Kluizenaar et al. 2007; Bluhm et al. 2007; Belojevic et al. 2008; Jarup et al. 2008; Barregard et al. 2009).

Besides, long-term exposure to traffic-related air pollution has been also associated with cardiovascular health (HEI 2010). There could be some interrelated biological pathways of long-term exposure to road traffic noise and air pollution leading to common cardiovascular endpoints. Therefore, traffic-related air pollution may confound the cardiovascular effects of road traffic noise in the long-term (Foraster et al. 2011). However, to our knowledge, few studies analyzing hypertension could consider air pollution (de Kluizenaar et al. 2007; Jarup et al. 2008).

We evaluated the cross-sectional association between outdoor residential modeled estimates of road traffic equivalent noise levels ($L_{night}$ and $L_{24h}$) and hypertension, adjusting for outdoor long-term modeled estimates of traffic-related air pollution in the city of Girona, north-eastern Spain, within the REGICOR-AIR project. We also evaluated the association by age groups and gender.

## METHODS

We evaluated 3,480 baseline participants (35-83 years old) corresponding to the population-based HERMES cohort (years 2003-2005). Trained nurses administered questionnaires on socio-demographic and lifestyle characteristics and collected information on general and cardiovascular health. They also took blood pressure measurements following the standard procedures of the project, based on the Joint National Committee VII.

The participants' addresses were automatically geocoded at 2 meters from the façade of the building and their precision was evaluated and corrected manually if necessary. The outdoor residential road traffic equivalent noise levels for the night, 9pm-7am, ($L_{night}$) and 24 hours ($L_{24h}$), and outdoor residential long-term averages of nitrogen dioxide ($NO_2$) concentrations were derived with a validated city-specific noise model (Environmental Noise Directive 2002/49/EC) and a land-use regression model, respectively.

Hypertension was defined as having a systolic blood pressure ≥140 mmHg or a diastolic blood pressure ≥90 mmHg or having hypertensive treatment. We performed multivariate logistic regression for the association between hypertension and road traffic noise. The relevant confounders were selected based on literature. The list included age, gender, socio-economic variables, diet, smoking, alcohol consumption, diabetes, body mass index, physical activity, family history of cardiovascular disease, heart rate, hyperlipidemia and air pollution exposure. The analyses were finally adjusted for those covariates that were associated with the outcome and the exposure in the bivariate analyses (with a p-value <0.2) and that contributed to the association in the multivariate analyses (with p-value<0.05 and a change in the effect estimate for road traffic noise of more than 10 %).

## RESULTS

Our population had an average age of 58 years (range 35-83). The prevalence of hypertension in our population was 42 %. The percentage of the population exposed to the different noise categories ($L_{night}$) was 13.8 % (for less than 50 dBA), 23.9 % (between 50-54 dBA), 38.6 % (between 55-59 dBA) and 23.7 % (60 dBA or more). The mean $NO_2$ level was 26.7 µg/m$^3$ (IQR=10.75 µg/m$^3$).

A non-significant association was found between night-time traffic-related noise and hypertension for an increase of 10 dB(A) in $L_{night}$ (OR=1.02; 95 %CI 0.86-1.20). Results for the relationship between hypertension and 24h traffic-related noise were similar for an increase of 10 dB(A) in $L_{24h}$ (OR=1.04; 95 %CI 0.88-1.22). This association remained unchanged after adjusting for $NO_2$. No significant associations were observed when using $L_{night}$ or $L_{24h}$ in categories of 5 dB and there was no clear trend in the OR with increasing noise. Results did not change in the stratified analyses by gender or age groups.

## CONCLUSIONS

The overall non-significant positive effect estimates are in line with some previous epidemiological studies. However, we could not confirm some of the reported significant effects observed in previous studies by gender or age groups. Further analyses will include the evaluation of coping behavior against noise and sensitivity analyses on the noise exposure assessment. Furthermore, we will also study the association between blood pressure and road traffic noise.

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# Exposure to road, aircraft and railway noise and the incidence of antihypertensives use

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## INTRODUCTION

As part of a monitoring program, the impact of aircraft noise from Amsterdam Airport Schiphol on the health of residents has been studied since 1992. With the acquisition of pharmacy data spanning the years 2000 to 2005 we were able to explore the impact of exposure to road traffic, railway and aircraft noise on the incidence of antihypertensives use and to study potential threshold levels in the exposure response relations. We applied an ecological study design, aggregating the medication data at the lowest possible aggregation level which was the 4-digit postal code area.

## METHODS

### Noise exposure

For the period 1995-2004, the Dutch National Aerospace Laboratory modeled annual average aircraft noise levels in $L_{den}$ in an area of 55 by 71 km based on actual flight tracks. All 580 postal code areas located within the boundaries of the aircraft noise map or dissecting it were included in the study. For railway and road traffic, the Netherlands Environmental Assessment Agency provided noise levels for 2004 (Blom 2008). These levels were used as a proxy for the noise exposure during the study period.

The location of each residential address within the study area was linked to the noise maps. The average noise exposure level for each postal code area was subsequently calculated from the noise levels of the addresses. Under the presumption that long-term noise exposure induces the additional use of antihypertensives, 5-year averaged noise levels over the 5 years preceding the onset of medication use were calculated. Also the exposure to 'total' transportation noise was calculated, combining aircraft, road, and railway noise at each address.

It is unclear whether the onset of antihypertensives use induced by noise has a threshold value. Additional noise exposure indicators were calculated with thresholds set to 45, 50, 55 or 60 dB for $L_{den}$. Residents living at addresses exposed to noise below a certain threshold level are assumed not to use antihypertensives due to noise exposure. Therefore, in this case the exposure was considered to be equal to the threshold level. The postal code area average noise exposure that is subsequently calculated is only influenced by the population exposed to noise levels above the assumed threshold.

### Pharmacy data

The Foundation for Pharmaceutical Statistics (SFK) routinely collects data on the use of pharmaceuticals. 299 of the 341 SFK member pharmacies gave permission to use their data which is 79 % of all community pharmacies within the study area.

For each of the 299 pharmacies we obtained information about the total number of prescriptions and the prescription of antihypertensives for each year of the period 2000-2005. Antihypertensives (C03A, C07AA, C07AB, C07B, C07C, C09A, C09B, C09C, C09D) were selected based on the guidelines of the Dutch College of General Practitioners (Wiersma et al. 2004). Since we were interested in first treatment for hypertension, residents using C07AA07, C09BB, C01AA05, C01DA or C08 were excluded, as these may indicate a deterioration of an underlying condition and not the start of a (first time) treatment.

SFK provided the incidence of medication use which was defined as ‘no similar prescription within the previous 12 months’. In addition, we received the year of birth, gender, and the 4-digit postal code number of the home address of the patients. Software changes at some of the pharmacies and missing data resulted in an incomplete dataset. Only pharmacies that delivered uninterrupted prescription information for the study period were included in the statistical analyses.

### Potential confounders

The mean socio-economic status (SES) of the residents and the demographic composition were available as potential confounders at postal code area level. Statistics Netherlands maintains records of the demographic composition at different aggregation levels online. A measure of SES at postal code area level based on income level, unemployment rate, and education level of its inhabitants is calculated every 4 years by the Netherlands Institute of Social Research (Knol 1998).

### Statistical analyses

Most statistical analyses were performed in “R”, in combination with WinBUGS (Lunn et al. 2000; Team RDC 2008). We investigated the within and between postal code area variance components by calculating the Intraclass Correlation Coefficient (ICC) of $L_{den}$.

To adjust for differences in the distribution of age and gender of the postal code area, indirect standardization was used to calculate the expected number of individuals using antihypertensives within each postal code area. Because the participating pharmacies did not constitute the total number of pharmacies in the study area, the expected number was based on the age and gender distribution of the individuals visiting the participating pharmacies to collect any prescribed medication in a given year.

A spatial regression model was used to assess the association between noise exposure levels and use of antihypertensives. It is assumed that the number of cases in an area follows a Poisson distribution. $RR_i$ is an area specific relative risk, which, in a general form, is given by:

$$\log(RR_i) = \beta_0 + \beta_{1,j}\ \text{Exposure}_{i,j} + \beta_{2,k}\ \text{year}_k + \beta_{3,l}\ \text{Confounder}_{i,l} + b_{struc,i} + b_{unstruc,i}$$

In the equation above, $\beta_0$ is the log baseline risk. $\beta_{1,j}$ represents the log risk ratios for exposure classes j=1...J, $\beta_{2,k}$ the log risk ratios between years k=1…K and $\beta_{3,l}$ the adjustment for potential confounders l=1…L. The final two terms consider extra variability resulting from unmeasured confounders, data anomalies, and model misspecification. It is expected that this extra variation is more similar for neighboring areas. Hence, the first term is a spatially structured term for any possible spatially unobserved confounders; the second is an unstructured term accounting for non-spatial contributions to the extra variation. An intrinsic conditional autoregressive prior is given to the spatially structured term. This ICAR prior depends on the number of neighboring postal code areas. An independent and identically distributed normal prior is given to the unstructured term (Besag et al. 1991). The fit of the models was compared using the Deviance Information Criterion (DIC) which indicates a balance between the fit of the data to the model and the complexity of the model (Spiegelhalter et al. 2002).

## RESULTS

The noise exposure levels in the study area are described in Table 1 supplemented with the Intra class Correlation Coefficient (ICC) for the various noise indicators, applying different threshold values.

**Table 1:** Exposure to aircraft, road, railway and total noise ($L_{den}$ in dB) for 580 postal code areas, and Intra Class Correlation coefficients

| | Road traffic | Railway traffic | Aircraft | Total noise |
|---|---|---|---|---|
| p5-25-50-75-95: | 36-48-52-55-59 | 25-25-36-44-53 | 27-38-44-48-53 | 43-51-54-57-61 |
| Mean ± s.d. | 50.6 ± 6.7 | 36.2 ± 10.0 | 42.4 ± 8.0 | 53.5 ± 5.3 |
| | | | | |
| Intraclass Correlation Coefficient (ICC) | | | | |
| Continuous | 0.61 | 0.85 | 0.99 | 0.63 |
| Threshold 45 dB | 0.43 | 0.52 | 0.94 | 0.54 |
| Threshold 50 dB | 0.34 | 0.39 | 0.87 | 0.45 |
| Threshold 55 dB | 0.29 | 0.28 | 0.85 | 0.37 |
| Threshold 60 dB | 0.27 | 0.18 | 0.88 | 0.35 |

Table 1 indicates that the noise exposure in the study area is dominated by road traffic noise. The ICC for aircraft noise of 0.99 indicates that almost all the variation in aircraft noise levels is found between the postal code areas, whereas the ICC of 0.61 for road traffic noise indicates that an important part of the variation in noise levels is contained within the postal code areas.

The ICC for the noise indicators with a threshold value decreases considerably for road and railway traffic with increasing threshold values, indicating that the introduction of a threshold value diminishes the exposure contrast between postal code areas.

The total number of patients in the database varies from 956,498 in 2001 to 985,622 in 2005. This is approximately 30 % of the total population. Within the 580 postal code areas the number of patients ranged between 0 to 15,230, with an average of 1,662. The large differences are due to industrial or rural postal code areas with few inhabitants and areas with few or no pharmacies included in the database.

The mean age and sex standardized incidence rate of antihypertensive use, expressed as a percentage of the total patient population visiting the participating pharmacies was 3.4 % (range 0 – 7.3 % for postal code areas).

The median SES ranking of the postal code areas is 0.63 indicating that the socio-economic status in the study area is, on average, higher than in all of The Netherlands. The percentage of non-western immigrants ranged from 0 % to 81 %, with the highest percentages found in the urban postal code areas.

No statistically significant association with SES was found for the antihypertensive use (relative risk of 1.01, 95% confidence interval (CI) 0.96-1.07). The relative risk for a 40 percent difference of non-western immigrants as part of the postal code population was 1.14 (95% CI 1.06-1.22).

The left hand graph in Figure 1 presents the relative risks of 5 dB exposure categories of road traffic, aircraft and total noise. The right hand graph in Figure 1 shows the relative risks of a 10 dB change in exposure using different threshold values.

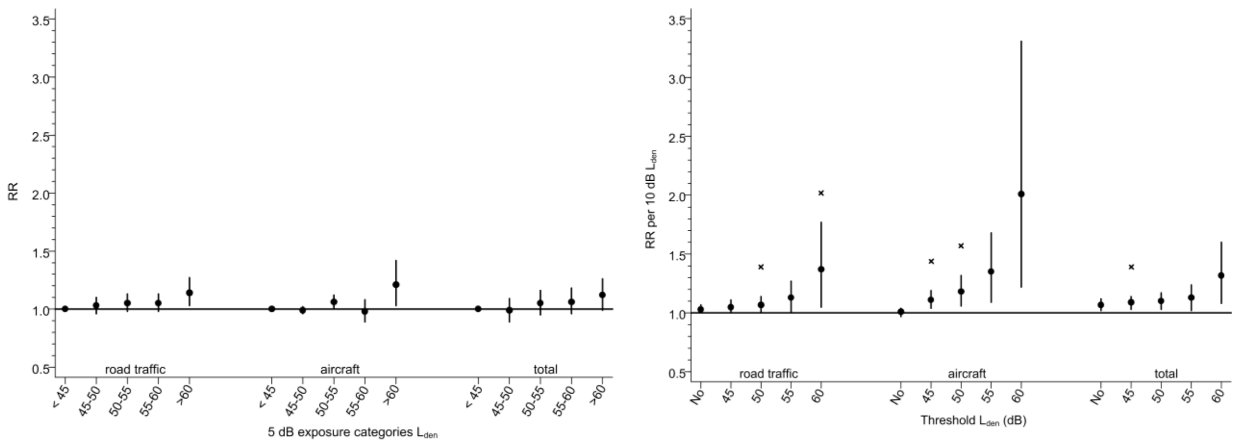


**Figure 1:** Posterior relative risks (RR) and 95% confidence intervals for the effect of 5 dB exposure categories (left) and for the effect of a 10 dB change in noise with different threshold values (right) for road traffic, aircraft, and total noise on antihypertensive use

Results for railway noise are not presented in Figure 1 since all relative risks have large confidence intervals, all statistically being non-significant. The models with the lowest DIC, the best balance between the fit and the complexity of the model, are marked with an x in the right hand graph of Figure 1. The results for these models are given in Table 2.

**Table 2:** Relative risks and 95% confidence intervals for the effect of a 10 dB change in road traffic, aircraft, and total noise on antihypertensives use for the models with the lowest DIC

| Source | Threshold (dB) | RR[1] per 10 dB $L_{den}$ | 95% CI | p-value |
|---|---|---|---|---|
| Road traffic | 50 | 1.07 | 1.00 - 1.14 | 0.047 |
| | 60 | 1.37 | 1.05 - 1.77 | 0.017 |
| Aircraft | 45 | 1.11 | 1.04 - 1.19 | 0.005 |
| | 50 | 1.18 | 1.06 - 1.32 | 0.003 |
| Total noise | 45 | 1.09 | 1.03 - 1.14 | 0.002 |

[1] Adjusted for year, socio-economic status and the percentage of non-western immigrants

The relative risks for the 5 dB exposure categories for antihypertensives are all below 1.25; there is a slight upward trend with increasing exposure (left hand graph in Figure 1). The highest exposure category for road traffic and aircraft noise (>60 dB $L_{den}$) differ statistically from the reference group. For road traffic noise two models with different thresholds values have an identical DIC. The model with a threshold value of 60 dB has a more precise estimate for the relative risk (p=0.017) than the model with a threshold value of 50 dB (p=0.047) (Table 2). Also for aircraft noise two models have the same DIC. The model with a threshold value of 50 dB has a more precise relative risk than the model with a threshold value of 45 dB. For total noise, the model with a threshold of 45 dB is the most optimal.

## DISCUSSION

The present study reveals associations between road traffic and aircraft noise and the incidence of antihypertensives. Exposure to railway noise was not related to the use of antihypertensives, possibly due to low levels of exposure. As expected, the relative risks of continuous noise exposure indicators tend to rise with increasing threshold (Figure 1). Because the major part of the population is exposed to lower noise levels, increasing the threshold with, for example 5 dB, will just slightly affect the incidence in the reference exposure group. Also the difference between the incidence in the newly created reference group and the subsequent exposure groups will change only slightly, but the range of the exposure indicator decreases resulting in an increased relative risk.

For road traffic noise, Barregard et al. (2009) observed, among residents living at least 10 years in the same dwelling for the exposure categories 51-55 dB and 56-70 dB, a prevalence ratio for self-reported antihypertensive drugs of 2.0 (95% CI: 0.99 to 3.8) and 2.5 (95% CI: 1.3 to 5.0) compared to a reference category of 45-50 dB. For self-reported use of medication for hypertension in a cross-sectional study, de Kluizenaar et al. (2007) observed an odds ratio of 1.03 per 10 dB (95% CI: 0.96 – 1.11) applying a threshold of 45 dB $L_{den}$. In their cohort study an odds ratio of 1.08 per 10 dB (95% CI: 0.95–1.23) for hypertension based on blood pressure and/or medication use was found. Jarup et al. (2008) observed an odds ratio of 1.10 (95% CI: 1.00-1.20) per 10 dB $L_{Aeq,24h}$ (threshold 45 dB) using the same definition of hypertension. An association was not found when the definition was restricted to use of antihypertensive medication only, which resulted in approximately 50 % fewer cases (Floud et al. 2011). A Swedish study reported an odds ratio of 1.90 (95% CI: 1.12-3.23) per 10 dB $L_{Aeq,24h}$ (threshold 45 dB) for self-reported doctor diagnosed hypertension (Bluhm et al. 2007). Rüdisser et al. (2008) observed in the age groups of 70 years and older living near a railway a statistically significant elevated odds ratio of 2.00 (95% CI 1.52-2.63) for registered antihypertensive use. No significant odds ratios were found for other age groups or for living near a major road. These recent studies differ in design, definition of medication use, applied noise indicators and thresholds which makes comparison of results difficult. In general, the results of our study (relative risk of 1.07 with a threshold of 50 dB and a relative risk of 1.37 with a threshold of 60 dB) are in line with the results of these recent studies.

Knipschild studied medication use due to aircraft noise exposure around Amsterdam Airport Schiphol in The Netherlands based on survey and pharmacy data (Knipschild & Oudshoorn 1977; Knipschild 1977) He found an increased use of cardiovascular drugs and antihypertensive drugs in the pharmacy data after an increase in aircraft noise exposure. A later survey study around Schiphol airport found increased self-reported use of antihypertensive and/or cardiovascular medication (odds ratio 1.30 per 10 dB $L_{den}$) (Franssen et al. 2004). A study around Cologne-Bonn airport in Germany, using registered data from compulsory sickness funds, found similar effects of nighttime aircraft noise on use of antihypertensive and cardiovascular medication (Greiser et al. 2007). Babisch & van Kamp (2009) concluded that there is sufficient evidence for an association between aircraft noise and high blood pressure and the use of cardiovascular medication. They suggested to use aircraft noise levels below 50 dB or 55 dB $L_{den}$ as reference category. They derived in their meta-analysis for hypertension an odds ratio of 1.13 per 10 dB $L_{den}$. In the study of Floud et al. the prevalence of antihypertensive use around Schiphol was associated with elevated odds ratios: 1.12 per 10 dB $L_{Aeq,16h}$ and 1.19 per 10 dB $L_{night}$ (Floud et al. 2011). Statistically significant odds ratios were observed for Heathrow Airport (UK) but not for the other four counties involved. For the incidence of antihypertensives we found that models with a threshold of 45 or 50 dB $L_{den}$ have the lowest DIC, a combination of a measure of fit with a measure of model complexity. The relative risk of the model with a threshold of 50 dB has the best precision (1.18 per 10 dB). This relative risk and the threshold of 50 dB correspond with the suggestion of Babisch & van Kamp (2009) and the results of Floud et al. (2011).

We investigated exposure-response relations between noise exposure from transport and the incidence of antihypertensives use and the impact of a possible threshold value. An ecological study design was applied as pharmacy data could only be aggregated at postal code level due to confidentiality regulations. As not all pharmacies in the study region participated, using the total population as the denominator might give erroneous results because the participation rate was not evenly distributed over the study area. Furthermore, at the borders of the study area, people will get their medications in pharmacies located just outside the study area. These factors could lead to an underestimation of the incidence proportions, which are not equally distributed over the study area. To avoid this potential bias, the total patient population of the participating pharmacies within each postal code was chosen as the denominator for the calculation of the incidence proportions. This measure is not hampered by the factors mentioned.

Exposure to transport noise was available for all residential addresses in the study area. This allowed the investigation of the variation in noise exposure within each postal code area as compared to the variation between the areas. For aircraft noise, the variation within the postal code areas was small. The average aircraft noise exposure of all residential addresses within a postal code area is therefore an accurate indicator of the exposure to aircraft noise of the population living within that area. As expected, the variation within postal code areas for road traffic and railway noise was much larger as exposure to both noise sources is a more local phenomenon influenced by the configuration of the roads and railways within each area and the type of buildings and other obstacles like noise barriers.

Due to the ecological design of the study, individual data could not be adjusted for individual risk factors, with the exception of gender and age. As an alternative, the relative risk of the exposure indicators were adjusted at the area level for the mean socio-economic status and the mean ethnicity of the postal code areas.

## CONCLUSIONS

We classified exposure, based on individual exposure data in an otherwise ecological study design. This method enabled us to take the variation in exposure within postal code areas into account and thereby reducing exposure misclassification. It also enabled evaluation of threshold levels in the exposure response relations. Significant positive associations were found between exposure to road traffic and aircraft noise and the use of antihypertensives. The results indicate evidence of threshold values. Routinely registered pharmacy data can be an important data source to explore possible impacts of environmental pollutants which, like transport noise, are spatially distributed.

## ACKNOWLEDGEMENT

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# Risk increase of cardiovascular diseases and impact of aircraft noise - the Cologne-Bonn Airport Study

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ABSTRACT

Since 1977 several investigators have demonstrated an impact of aircraft noise (AN) on hypertension and/or cardiovascular diseases (CD). A preceding study in the vicinity of Cologne-Bonn International Airport (CBIA) showed an increase of amount of cardiac drugs prescribed with increasing AN. Geo-referenced environmental noise data (aircraft, road, railroad) were linked to hospital discharge diagnoses of 1,020,528 persons living in the vicinity of CBIA insured in 8 German sickness funds (residential addresses geo-referenced) in a case-control design. Study population came to more than 55 % of the total population of the study region (Cologne City and 2 adjacent counties). Confounders were in addition to age environmental noise, prevalence of social welfare recipients of residential quarters and interaction of AN*age. With increasing age risk increase for all CD is decreasing. Increases are larger in women. For night-time (11 p.m.-1 a.m.) AN of 50 dBA and age of 50 the odds ratios are for all CD in men 1.22 (95% CI 1.08-1.39), in women 1.54 (95% CI 1.36-1.75); for acute myocardial infarction in men 1.18 (95% CI 0.90-1.54), in women 1.54 (95% CI 1.10-2.18); for heart failure in men 1.52 (95% CI 1.22-1.88), in women 1.59 (95% CI 1.29-1.95); for stroke in men 1.36 (95% CI 1.00-1.85), in women 1.36 (95% CI 1.00-1.84). Analyses stratified by prevalence of social welfare quartile showed no risk increase in highest quartile, although prevalence of all CD was increasing with prevalence of social welfare recipients. This major study contributes additional evidence linking AN to cardiovascular diseases.

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# Effects of workplace noise exposure during pregnancy. Systematic review with Meta-analysis and Meta-regression

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## ABSTRACT

The aim of this review was to summarize published epidemiological studies on the effects of workplace noise exposure during pregnancy.

**Methods.** An extensive search of the literature was conducted from Medline and Embase. Twenty-seven studies published in French or in English between 1970 and 2008 were selected. Each study was systematically evaluated regarding the following aspects: design, size of the study; external validity; population studied (method of selection, participation rate); pregnancy outcome (definition and measurement); noise exposure (definition, comparison group, measurement method); and confusion control (personal factors and other occupational exposures). For each pregnancy outcome, if the results could be combined, a meta-analysis was performed and when the number of studies was sufficient, a meta-regression was done. We searched for publication bias using the funnel plot tool. Finally, the strength of the evidence was classified as: strong, sufficient, suspicion or data do not allow a conclusion; after evaluation of the following criteria: biologic plausibility, statistical accuracy, validity and coherence.

**Results.** In the presence of noise exposure in the workplace, sufficient evidence (1.27; 95%CI:1.01-1.59) of increase for the risk of small-for-gestational-age was noted. A suspicion of increased risk exists for: spontaneous abortion (1.06; 95%CI:0.97-1.16), preterm delivery (1.13; 95%CI:0.57-2.24), pre-eclampsia (1.12; 95%CI:0.78-1.59) and gestational hypertension (1.42; 95%CI:0.83-2.44). Finally, the data do not allow a conclusion regarding the risks of stillbirth, congenital anomalies and low birth weight.

**Conclusion.** Although a modest increase in risk (27 %), the frequencies of noise exposure during pregnancy and small-for-gestational-age births, could result in a non-negligible public health impact.

# Noise sensitivity - medical, psychological and genetic aspects

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## INTRODUCTION

Noise sensitivity refers to physiological and psychological states of any individual, which increase the degree of reactivity to noise (Job 1999). It constitutes a trait covering attitudes to noise in general and it is a predictor of annoyance (van Kamp et al. 2004; Stansfeld 1992). Noise sensitivity may be directly related to outcomes of noise exposure (Smith 2003). A significant correlation has been found between subjective health and noise exposure in the noise-sensitive group, while no significant correlation were observed in the insensitive group. Thus, the adverse health effects may exist especially in the sensitive group (Kishikawa et al. 2009). In women noise sensitivity has been related to slower habituation of heart rate responses to loud threatening noises (Stansfeld 1992) and to cardiac health complaints (Nivison & Endresen 1993). Blood pressure increase has correlated with self-reported sensitivity to noise (Otten et al. 1990). In field conditions several hours of exposure to road noise at level 60 dB has shown to cause more pronounced blood pressure reactions in noise sensitive subjects than in noise insensitive subjects (Ising 1983 in Ising & Kruppa 2004). However, in Austrian Tyrol area studies noise sensitivity was non-significantly or even inversely associated with blood pressure readings or self-reported hypertension or treatment (Lercher et al. 2011). A significant noise effect on subjective sleep quality has been reported among noise sensitive subjects (Öhrström et al. 1988) and noise sensitivity has altered self-reported sleep disturbance attributed to noise (Miedema & Vos 2003). Correlations have been found between noise sensitivity and subjective sleep quality (Marks & Griefahn 2007; Nivison & Endresen 1993) in terms of difficulty to fall asleep, body movements, poor restoration and decreased calmness (Marks & Griefahn 2007).

Noise sensitivity has been associated with health-related quality of life and annoyance and sleep disturbance have mediated the effects of noise sensitivity on health (Shepherd et al. 2010). The risk of health effects caused by noise may be higher for noise sensitive individuals compared with non-noise sensitive individuals. A cardiovascular disease may be an example of outcomes (Figure 1).

However, determinants and characteristics related to noise sensitivity are not very well known. There are studies on noise and mortality, but previous studies on the association of noise sensitivity with mortality were not available according to the literature available. Studies on the role of genetic factors in noise sensitivity prior to this study were not available, but heritability of acoustic startle response (Brocke et al. 2006) has been studied. The aim of the present study was to investigate the association of noise sensitivity with hearing ability, specific somatic and psychological factors and mortality and to study the genetic component of noise sensitivity. The central results presented here have been published previously (Heinonen-Guzejev 2008; Heinonen-Guzejev et al. 2004, 2005, 2007, 2011).

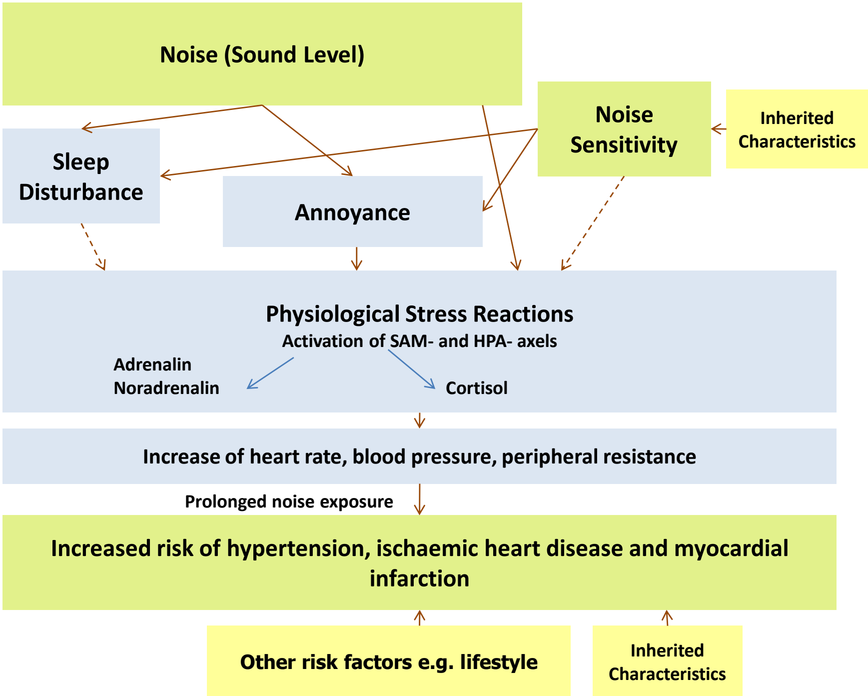


**Figure 1:** Model of the schematic pathways of the possible relationship of noise sensitivity with development of cardiovascular disease

## MATERIALS AND METHODS

The study is based on the older Finnish Twin Cohort of same-sex twin pairs born before 1958 with both members alive in 1967 who had all been sent questionnaires in 1975 and 1981. In 1988 a questionnaire on noise and related factors was sent to 1005 twin pairs discordant for hypertension. 1495 individuals (688 men, 807 women) aged 31-88 years replied. For 573 twin pairs (131 MZ and 442 DZ) both twins had answered the question on noise sensitivity. Self-reported noise sensitivity, hearing ability and hypertension were obtained from the questionnaire study in 1988 and other somatic and psychological factors from the questionnaire study in 1981 for the same individuals. To evaluate the stability and validity of noise sensitivity, a new questionnaire was sent in 2002 to a sample of the subjects who had replied to the 1988 questionnaire. A subsample of thirty-eight elderly women with noise sensitivity response from 1988 had audiometric data from 2000 to 2001 (Heinonen-Guzejev et al. 2011).

Noise sensitivity was investigated using a short question (Heinonen-Guzejev et al. 2004, 2005, 2007). In the 2002 questionnaire the Weinstein's Noise Sensitivity Scale was also used. Lifetime noise exposure was evaluated using three questions about noise exposure at home, at work and noisy leisure time hobbies. A lifetime noise exposure scale was formed by summing these three items (Heinonen-Guzejev 2008). Noise map information was available only for 218 subjects who lived in the Helsinki Metropolitan, but it was not used in these analyses. In our previous study aircraft noise maps were consistently associated with the self-report of noise exposure (Heinonen-Guzejev et al. 2000). All questions used are presented in detail elsewhere (Heinonen-Guzejev 2008; Heinonen-Guzejev et al. 2004, 2011).

Data on deaths and causes of death were obtained from record linkage to the nationwide Finnish death register at Statistics Finland using the unique personal identity numbers given to all residents of Finland. All deaths that occurred among the study population from 1 January 1989 to 31 December 2003 were classified as being due to all causes (n = 382), to cardiovascular diseases (ICD 9 codes 390–459, ICD10 I00–I99) (n = 193), to coronary heart disease (ICD 9 codes 410–414, ICD10 codes I20–I25) (n = 111) and to other causes than cardiovascular diseases (n =189). Autopsy had been made for 19 % of the deceased (Heinonen-Guzejev et al. 2007).

Cohen's coefficient of agreement for nominal scales, Pearson chi-square and logistic regression models were used. The Cox proportional hazards regression model was used to evaluate the risk of mortality in relation to noise sensitivity (Heinonen-Guzejev 2008; Heinonen-Guzejev et al. 2007). To take into account the sampling of twin pairs, the possible lack of statistical independence of twins in a twin pair, robust estimators of variance were computed with the cluster option in Stata to derive correct confidence intervals (Williams 2000). Standard model fitting methods were employed using Mx, a program for analysis of twin and family data (Neale et. al. 2003) fitting directly to the raw ordinal data.

## RESULTS

The short question on noise sensitivity showed good validity when correlated with the Weinstein’s multi-item noise sensitivity scale. Noise sensitivity was relatively stable between 1988 and 2002 questionnaires. Of all subjects who had answered the question on noise sensitivity, 38 % were noise sensitive (36 % of women and 41 % of men). The overall tendency was decreasing noise sensitivity with age (age range 31–70 years). The age related differences in noise sensitivity were statistically significant among men and women (Heinonen-Guzejev 2008; Heinonen-Guzejev et al. 2004).

### Noise sensitivity and hearing disability

Noise sensitivity was associated with self-reported hearing disability among all subjects (adjusted OR 1.55, 95% CI 1.14–2.12) and among women (adjusted OR 1.55, 95% CI 1.19–3.04), but no-more significantly among men (adjusted OR 1.55, 95% CI 0.86–1.98). Noise sensitivity was associated with self-reported hearing disability with evidence for a dose-response relationship. The association was primarily seen among younger subjects (50 years or less) (Heinonen-Guzejev et al. 2011).

However, noise sensitivity was not associated with auditory acuity. The average of thresholds at frequencies of 0.5–4 kHz in the better ear among elderly noise sensitive women was 27.6 dB (95% CI 20.0–35.3) and among non-noise sensitive women 31.5 dB (95% CI 27.3–35.6). The difference between these two groups was not statistically significant (Pr = 0.18). However, statistical significance was reached for the threshold differences at frequencies of 0.125 and 8 kHz. An analysis of mean BEHL (better ear hearing levels) at different frequencies showed that noise sensitive female subjects tended to have somewhat better hearing thresholds than non-noise sensitive ones (Heinonen-Guzejev et al. 2011).

Noise sensitivity did not modify the association of self-reported hearing disability with the self-reported history of occupational noise exposure. Self-reported history of noise exposure during leisure time hobbies was associated with self-reported hearing disability among younger non-noise sensitive subjects (Heinonen-Guzejev et al. 2011).

### Noise sensitivity and somatic and psychological factors

Noise sensitivity was significantly associated with hypertension, stress, hostility, use of sleeping pills, tranquillizers and pain relievers, former smoking and emphysema, even when lifetime noise exposure was adjusted for. The age and sex adjusted association of neuroticism with noise sensitivity was significant, but in the multivariate analyses became non-significant. This weakening of the association may represent adjustment for intermediary variables (stress and hostility). The results indicate that noise sensitivity has both somatic and psychological components (Heinonen-Guzejev et al. 2004).

In analyses performed separately among women and men, in women noise sensitivity was associated significantly with stress, hostility and hypertension, while in men it was associated with stress, emphysema and use of sleeping pills and tranquillizers (Heinonen-Guzejev et al. 2004).

### Noise sensitivity and mortality

**Cardiovascular mortality** was significantly increased among noise sensitive women (hazard ratio 1.80, 95% CI 1.07–3.04). Among men there was no statistically significant effect (hazard ratio 0.80, 95% CI 0.45–1.43) (Table 1). Both in women (hazard ratio 1.13, 95% CI 0.66-1.92) and in men (hazard ratio 1.19, 95% 0.63-2.25) reporting lifetime noise exposure, cardiovascular mortality was increased, but not statistically significant (Table 1) (Heinonen-Guzejev et al. 2007).

**Table 1:** Adjusted hazard ratios for cardiovascular mortality among women and men

| | | Women | | Men | |
|---|---|---|---|---|---|
| | | Age-adjusted hazard ratio | Full model* | Age-adjusted hazard ratio | Full model* |
| **Noise Sensitivity** | No | 1.00 | 1.00 | 1.00 | 1.00 |
| | Yes | 1.75 | **1.80** | 0.88 | 0.80 |
| | 95% CI | 1.15-2.67 | **1.07-3.04** | 0.54-1.44 | 0.45-1.43 |
| **Hypertension** | No | 1.00 | 1.00 | 1.00 | 1.00 |
| | Yes | 2.06 | **2.58** | 1.71 | 1.44 |
| | 95% CI | 1.32-3.21 | **1.33-4.98** | 1.06-2.77 | 0.81-2.56 |
| **Lifetime Noise Exposure** | No | 1.00 | 1.00 | 1.00 | 1.00 |
| | Yes | 1.21 | 1.13 | 0.93 | 1.19 |
| | 95% CI | 0.81-1.81 | 0.66-1.92 | 0.59-1.47 | 0.63-2.25 |

*Adjusted for age, hypertension, smoking and emphysema

**Coronary heart mortality** was increased, but not statistically significant among noise sensitive women (hazard ratio 2.03; 95% C.I. 0.94-4.37), with no evidence for an increase in noise sensitive men (Table 2). In men reporting lifetime noise exposure coronary heart mortality was increased but not statistically significant (hazard ratio 1.52; 95% CI 0.73-3.18), and it was higher than in women (hazard ratio 1.08, 95% CI 0.48-2.44) (Table 2) (Heinonen-Guzejev et al. 2007).

Taking into account factors known to affect mortality in general (education, body mass index, physical activity, alcohol consumption, passing out due to alcohol use more than once in a year) did not change the results for any of the cause of death categories (data not shown) (Heinonen-Guzejev et al. 2007).

**Table 2:** Adjusted hazard ratios for coronary heart mortality among women and men

| Women | | | | Men | |
|---|---|---|---|---|---|
| | | Age-adjusted hazard ratio | Full model* | Age-adjusted hazard ratio | Full model* |
| **Noise Sensitivity** | No | 1.00 | 1.00 | 1.00 | 1.00 |
| | Yes | 1.69 | 2.03 | 0.89 | 0.89 |
| | 95% CI | 0.89-3.21 | 0.94-4.37 | 0.49-1.60 | 0.45-1.73 |
| **Hypertension** | No | 1.00 | 1.00 | 1.00 | 1.00 |
| | Yes | 1.89 | 2.32 | 1.59 | 1.29 |
| | 95% CI | 1.02-3.51 | 0.91-5.91 | 0.90-2.82 | 0.67-2.51 |
| **Lifetime Noise Exposure** | No | 1.00 | 1.00 | 1.00 | 1.00 |
| | Yes | 1.24 | 1.08 | 1.33 | 1.52 |
| | 95% CI | 0.69-2.23 | 0.48-2.44 | 0.77-2.33 | 0.73-3.18 |

*Adjusted for age, hypertension, smoking and emphysema

Table 3 shows the interactions of noise sensitivity and lifetime noise exposure with coronary heart and cardiovascular mortality in women. Among men there was no statistically significant effect (data not shown). **Coronary heart mortality** was significantly increased among noise sensitive women reporting lifetime noise exposure, but not among those not reporting lifetime noise exposure. For coronary heart mortality the interaction of noise sensitivity and lifetime noise exposure was statistically significant (p for interaction 0.022). **Cardiovascular mortality** was significantly increased among noise sensitive women both reporting and not reporting lifetime noise exposure, and the point estimate of the hazard ratio was higher among women reporting lifetime exposure. The interaction was not statistically significant (p for interaction 0.076) (Heinonen-Guzejev 2008; Heinonen-Guzejev et al. 2007).

**Table 3:** Interaction of noise sensitivity and lifetime noise exposure with coronary heart and cardiovascular mortality (age adjusted) in women and number of deaths (n) and total number of female subjects (N)

| **Coronary heart mortality** | | | | **Cardiovascular mortality** | | | |
|---|---|---|---|---|---|---|---|
| **Lifetime Noise Exposure** | | **Noise Sensitivity** | | **Lifetime Noise Exposure** | | **Noise Sensitivity** | |
| | | No | Yes | | | No | Yes |
| No | n/N | 17/252 | 7/156 | No | n/N | 31/252 | 17/156 |
| | Hazard ratio | 1.00 | 1.36 | | Hazard ratio | 1.00 | **2.10** |
| | 95% CI | | 0.48-3.83 | | 95% CI | | **1.03-4.28** |
| Yes | n/N | 3/134 | 11/127 | Yes | n/N | 9/134 | 20/127 |
| | Hazard ratio | 0.64 | **3.11** | | Hazard ratio | 0.84 | **2.93** |
| | 95% CI | 0.20-2.11 | **1.19-8.10** | | 95% CI | 0.38-1.82 | **1.39-6.19** |
| p for interaction | | **0.022** | | p for interaction | | 0.076 | |

## Genetic component of noise sensitivity

Monozygotic twin pairs were more similar with regards noise sensitivity than dizygotic twin pairs. The intraclass correlations for noise sensitivity in MZ pairs was 0.36 (95% CI 0.16–0.52) and in DZ pairs 0.19 (95% CI 0.07–0.31). Excluding those pairs in which one or both were hearing impaired did not significantly change the correlations between twins in MZ and DZ pairs. Correlations for male and female pairs did not differ significantly statistically (Heinonen-Guzejev et al. 2005).

Quantitative genetic modeling indicated significant **familiality**. The E model could be rejected meaning that family factors are needed to account for the pairwise distribution of the data. The remaining models (AE, ACE and CE) provided adequate fit to the data. In the ACE model, the estimate for C was very small (3 %), and the fit of the AE model was better than the CE model when either is compared to the ACE model. Hence the best-fitting model was the AE model, which indicates that genetic factors (A) and unique environmental factors (E) (not shared with family members) account for the variability in noise sensitivity in the population. The estimate for the proportion of variance accounted for by genetic factors was 36 %, with the remainder due to unique environment factors (Figure 2) (Heinonen-Guzejev et al. 2005).

When twins with impaired hearing were excluded, the estimate of the proportion of variance accounted for by genetic factors was 40% in an AE model (Figure 2) and the CE model was rejected, as it fit significantly worse than the ACE model (p = 0.05) (Heinonen-Guzejev et al. 2005).

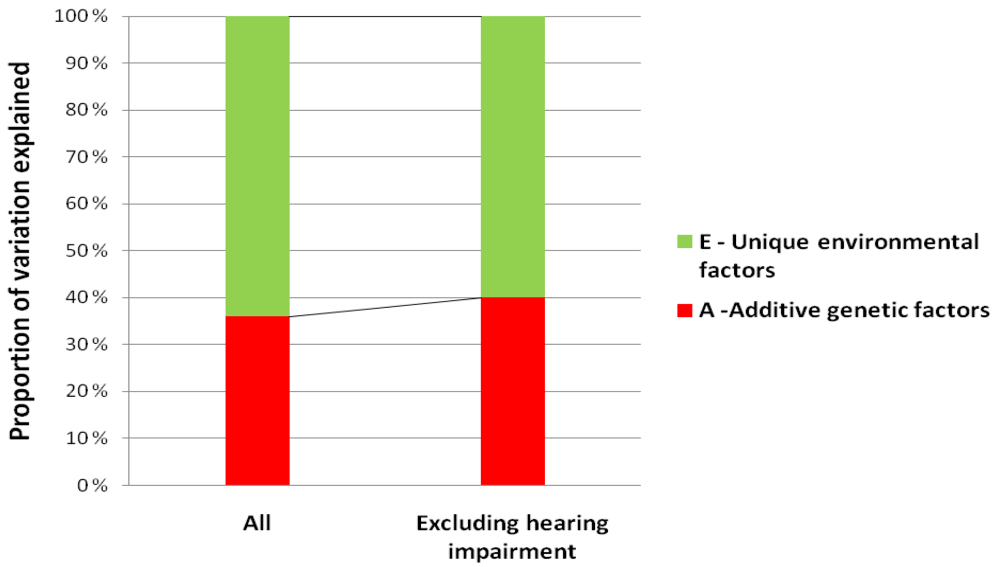


**Figure 2:** Proportional estimates of additive genetic factors (A) and unique environmental factors (E) on noise sensitivity in Finnish Twins.

## DISCUSSION

In this study, noise sensitivity was not associated with auditory acuity among elderly women. However among younger subjects (50 years or less), it was associated with self-reported hearing disability, with evidence for a dose-response relationship. In previous studies noise sensitivity has not either been associated with auditory acuity (Ellermeier et al. 2001; Stansfeld 1992). The effects observed previously have suggested noise sensitivity to reflect a judgemental, evaluative predisposition towards the perception of sounds (Ellermeier et al. 2001). Highly noise sensitive women have rated the loudest tones as louder and the softest tones as softer than low noise sensitive women (Stansfeld et al. 1985). The lack of an association between noise sensitivity and auditory acuity in elderly subjects in this study may also indicate an increasing role of neural presbycusis with age, whereby the loudness function may turn to a gentler one.

In previous studies, too, noise sensitivity has been associated with hypertension (Ising 1983 in Ising & Kruppa 2004; Otten et al. 1990) and stress (Zimmer & Ellermeier 1999). It has been associated with sleep quality (Marks & Griefahn 2007; Nivison & Endresen 1993; Öhrström et al. 1988). However, our finding that emphysema is associated with noise sensitivity is new. Overall, emphysema was strongly associated with former and current smoking. Noise sensitivity was also associated with former smoking. The cross-sectional nature of this study does not permit the resolution of the causal nature of this association.

Noise sensitivity was associated significantly with hypertension in women, but not in men. Cardiovascular mortality was significantly increased among noise sensitive women, but among men there were no statistically significant effects. Previous studies have also found some gender differences in the association of noise sensitivity with cardiovascular disease. In women cardiovascular problems have been related to noise sensitivity (Nivison & Endresen 1993), but in men noise sensitivity has not increased the risk of ischaemic heart disease (Babisch et al. 1999), which is in accordance with the present study.

Genetic factors and unique environmental factors account for the variability in noise sensitivity in the population. The AE model provided an estimate of heritability of 36 %. Noise sensitivity aggregates in families. The genetic component of noise sensitivity was studied among twin pairs discordant for hypertension, and noise sensitivity was associated with hypertension, which may have led to an underestimation of the genetic component. Results of the present study can provide new information about the heritability of noise sensitivity that may help in the search for specific genes or sets of genes underlying noise sensitivity. Further large-sample twin studies are needed to investigate the nature of the genetic component of noise sensitivity.

## CONCLUSIONS

Noise sensitivity is not associated with auditory acuity in elderly subjects, but it is associated with self-reported hearing disability particularly among younger subjects. It does not modify the association of self-reported hearing disability with the history of occupational noise exposure. Noise sensitivity has both somatic and psychological components and it may be a risk factor for cardiovascular mortality in women, but not in men. Noise sensitivity aggregates in families and probably has a genetic component.

## ACKNOWLEDGEMENTS

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# Patterns of physiological and subjective responses to vehicle pass-by noises, depending on age, gender, and personality traits

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## INTRODUCTION

In former laboratory studies, we compared the perceived sound quality of pairs of noise recordings (traffic noises as well as single pass-by noises) adjusted to the same $L_{eq}$ of 83 dBA that resembled each other except for one aspect, e.g. the same car passing by either with petrol or diesel engine (Notbohm et al. 2002; Schwarze et al. 2003). In most pair-wise comparisons, stronger physiological responses were accompanied by more negative judgments on the respective sound. But there were a few exceptions in which the sound creating a stronger physiological arousal was judged more favorable (Gärtner et al. 2003).

This seemingly contradictive result might be understood better in terms of the psychological model of affective reaction to external stimuli illustrated in Figure 1: Any sensory stimulus triggers physiological and cognitive responses which can be assigned to the categories “activation” and “pleasantness” resulting in four different tendencies of judgment (Bradley & Lang 2000; Västfjäll et al. 2002). Most traffic noises can probably be perceived as activating *and* unpleasant, but it is evident that there are single pass-by noises (e.g. from sport or luxury cars) that at least by some people are judged to be activating as well as pleasant. With regard to our studies mentioned above carried out with young male students, we concluded from some remarks that the young subjects perceived these specific car noises as sounding more “sportive” or “powerful” leading to a rather pleasant activation.

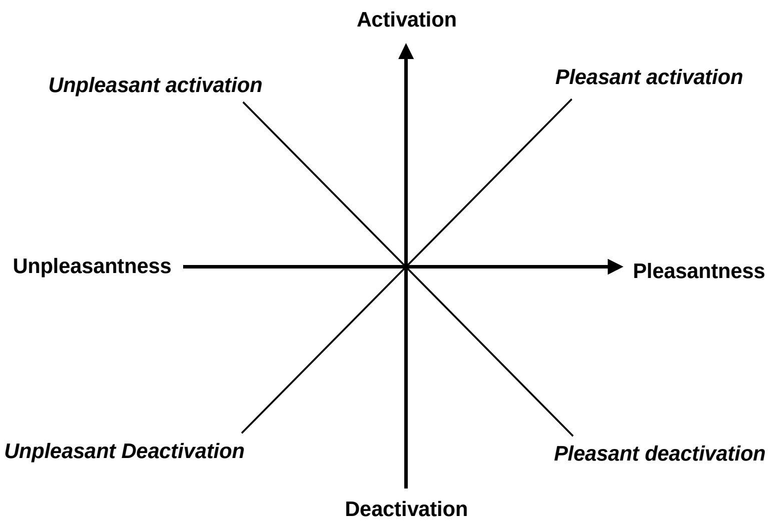



**Figure 1:** Two-dimensional model of affective reactions to external stimuli – activation and pleasantness

The present study is outlined to examine the effects of age and gender on the type of affective responses to vehicle pass-by noises more systematically using sounds from the previous experiments. However, far more factors are involved in shaping the individual response to sound. Already on the physiological level, there is much evidence that responses are generally stronger with persons who display certain personality traits such as noise sensitivity (Stansfeld & Shine 1993), neuroticism (Belojevic & Jakovljevic 2001), negative affectivity (Smith & Rich 2000) or preferred coping strategies (Job 1999). Therefore, in the present study relevant personality traits are assessed additionally in order to examine their possible relationship to age or gender.

METHODS

## Sample

The sample consisted of 66 subjects, who received a financial gratification for their participation. The subjects had to fulfill some preconditions: good state of health, especially no cardiovascular diseases, good hearing, no intake of medical drugs, alcohol, or caffeine on the day of the experiment, and no lack of sleep.

As the intention was to investigate the influence of age and sex, female and male subjects from two age groups were recruited: younger group 20–30 years, older group 40–55 years. Table 1 shows the distribution of subjects to the four subgroups.

**Table 1:** Subgroups of the sample (n = 66)

| gender \ age | 20–30 ys | 40–55 ys |
|---|---|---|
| male | 16 | 17 |
| female | 17 | 16 |

## Physiological measures of effect

Four different physiological variables were measured during the experiment:

- finger-pulse amplitude (FPA) as a measure of the peripheral blood circulation
- skin conductance level (SCL) as a measure of the electric skin activity
- electro-myogram of the forearm (EMG) as a measure of the electric muscle activity
- heart rate (HR) as a measure of the heart beats per minute being also the base for calculating the heart rate variability.

All these parameters reflect changes of the physiological state of the body in a dimension of activation of the vegetative system elicited by external stimuli as well as by physical tension or emotional arousal. They have proven to be reliable measures of noise effects, but naturally respond also non-specifically to other stressors.

The physiological measurements were taken continuously during the experiment. For the statistical analysis, means for specific time intervals (2–5 s) for each subject were calculated and transformed into percentages in relation to the baseline value of 100% (mean of the last 30 s rest before start of the sound). In the following, we will just give results on FPA and SCL.

## Subjective evaluation of the sounds

In addition to the physiological measurements, the subjective evaluation of the sound stimuli by the subjects was assessed by several questionnaires.

One questionnaire included three general judgments which had to be rated on interval scales. For each sound, the subject had to mark the degree to which s/he feels unpleasant or pleasant respectively deactivated or activated on scales ranging from –4 to +4. These two variables are labeled “pleasantness” and “activation”. Additionally we asked a summarizing question on how much the person liked the sound all in all with a bipolar scale ranging from 1 (“not at all”) to 9 (“as much as possible”).

Furthermore, the subjects were asked to rate the extent to which 23 adjectives applied to each noise on scales from 1 (“not at all”) to 9 (“as much as possible”). Using factor analysis these adjectives were summarized to four factors labeled unpleasantness, noisiness, danger and sportiness. These factors were converted into scales by calculating the means ranging from 1 to 9 from all items loading highest on the respective factor.

### Assessment of moderating variables

As mentioned above, personality traits which might influence the individual reaction to noise were assessed by means of relevant questionnaires, namely:

- Noise Sensitivity Scale (Weinstein 1978)
- Individual attitudes towards the acoustical environment (Notbohm 2010)
- NEO-Five Factor Inventory (Costa & McCrae 2006)
- Sensation Seeking Questionnaire (Zuckerman et al. 1978).

### Experimental procedure

Each subject took part in one experimental session in the anechoic chamber. At the beginning there was a 15 min. period of silence for relaxation and habituation to the situation. Each sound lasted 2 min. and was followed by a silent period of relaxation of 4 min. The participants listened to ten sounds altogether, so the whole session lasted for 71 minutes totally. The first two sounds were given for familiarization as former studies had shown that the reactions to the first sounds were quite extreme sometimes. The following eight sounds were varied in order.

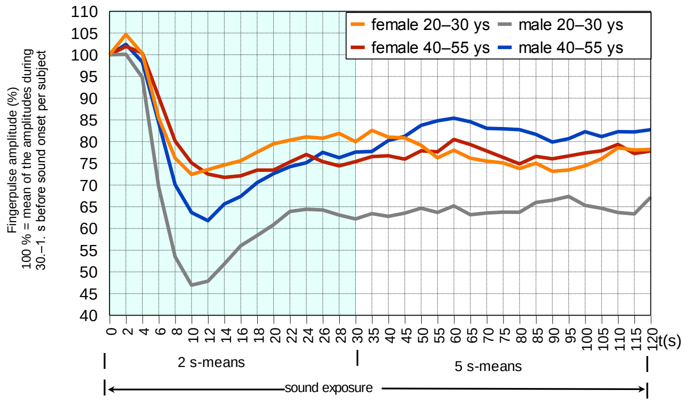
All noises were single car pass-by noises varying in three driving conditions: two variations of a car driving by 50 km/h in the 2nd gear with acceleration (original recording and modification of the engine sound), two variations of a car driving by 70 km/h in the 3rd gear with constant speed (original recording and modification of the tires) and four variations of a brake – idle – acceleration sequence. The sound level of all noises was adjusted to the same $L_{eq}$ of about 83 dBA.

After presentation of the last noise, the electrodes were taken off. Then, after a short break the subjects had to fill in the questionnaires for the subjective evaluation while the noises were repeated in a shortened version.

## PHYSIOLOGICAL AND SUBJECTIVE RESPONSES TO THE SOUNDS

### Finger-pulse amplitude

The typical response of the finger-pulse amplitude to noise exposure is a decrease of peripheral vascular circulation displayed as a sharp drop as compared to the baseline followed by a slow return towards the baseline during further exposure. Figure 2a shows the mean curves of the four subgroups of the sample as an average over all eight experimental sounds. As the initial response is the most interesting, the first 30 s are presented on a larger scale. The young men (grey line) and the older men (blue line) clearly show the strongest responses with a maximum drop of the FPA below 50% respectively 65% of the baseline. Figure 2b summarizes the mean change of the finger-pulse amplitude during the first 30 s for all three subgroups. Statistically there is a significant main effect of age (p<0.01) and also of gender (p<0.001) as well as an interaction age x gender (p<0.001).



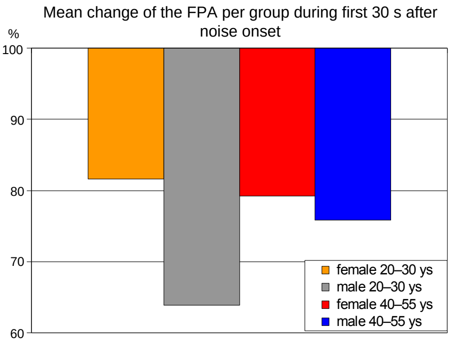
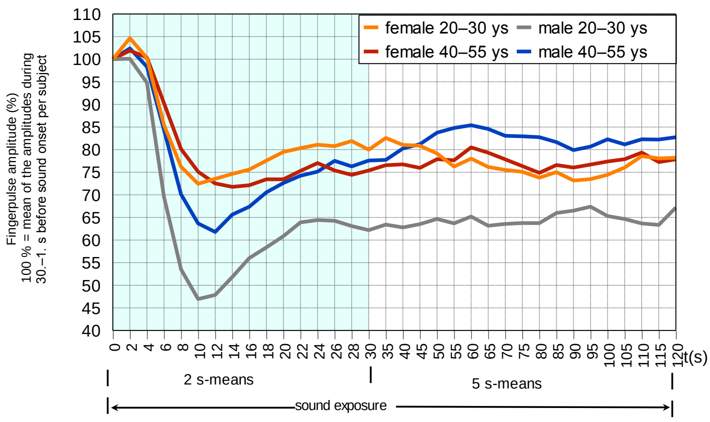




**Figure 2a:** Changes of the FPA for the four subgroups in relation to the baseline during noise exposure of 2 min. (means of all 8 experimental sounds)

**Figure 2b:** Mean value of each sub-group for the change of the FPA in relation to the baseline during the first 30 s after noise onset

## Skin conductance level

The skin conductance level is expected to rise in situations of physiological arousal. From Figure 3a it can be seen that all four subgroups show a very strong increase of the SCL in the first 10 s after noise onset, but the groups differ in the strength of re-sponse: The older women (red line) display the strongest response, followed by the younger women (orange line). The two male groups do not differ very much in their course of response. Figure 3b gives the numerical mean values of the rise of the SCL during the first 30 s. Statistically, there is a main effect of gender (p<0.001).



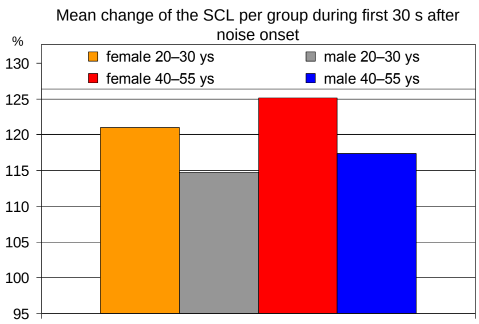




**Figure 3a:** Changes of the SCL for the four subgroups in relation to the baseline during noise exposure of 2 min. (means of all 8 experimental sounds)

**Figure 3b:** Mean value of each subgroup for the change of the SCL in relation to the baseline during the first 30 s after noise onset

## Subjective noise evaluation

As mentioned above, the subjects had to rate how much they like each noise ranging from 1 ("not at all") to 9 ("as much as possible"). Figure 4 shows the mean judgments for the different subgroups based on the totality of all experimental noises.

It is obvious that the noises are not liked very much – all the mean values in Figure 4 are in a range between 2 and 3. Nonetheless, women dislike the noises more then men (2.55 vs. 2.92), and the older dislike them more than the younger ones (2.64 vs. 2.83). For the four subgroups, there is a clear gap between the older women (2.31) and the other groups: young women (2.76), young men (2.89) and older men (2.94). As a result from variance analysis there is a significant main effect of gender (p<0.001) and an interaction of age and gender (p<0.05).

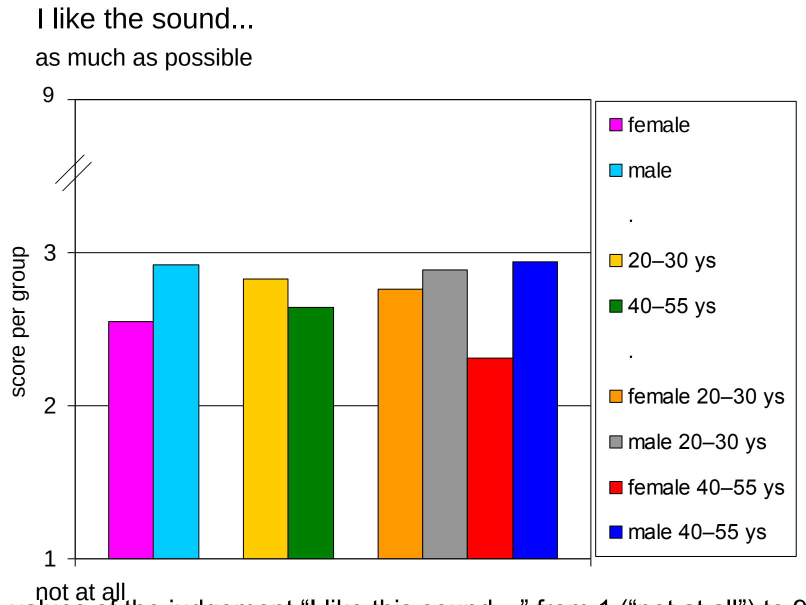



**Figure 4:** Mean values of the judgement "I like this sound…" from 1 ("not at all") to 9 ("as much as possible") on all experimental sounds for different subgroups: male vs. female (left), young vs. older (middle) and all four subgroups regarding age and gender

With regard to the other two general judgments, "pleasantness" and "activation", the results are similar: The older women feel clearly more unpleasant than the other groups, and the older women (and also the older men) experience more activation by the noises than the younger groups. For both variables, the main effect of "age" is significant (p<0.05).

Finally, the results of the scales extracted by factor analysis from the adjective list are shown in Figure 5. For the scale "annoyance", there is a main effect of gender (p<0.05) as well as of age (p<0.001) and an interaction between age and gender (p<0.05). The female subgroups rate the sounds higher than the male subgroups in terms of "annoyance", and the older subgroups give higher ratings than the younger ones, with the older females rating the sounds as the most annoying.

For the scale "noisiness", a main effect of gender is shown (p<0.01). An interaction between age and gender misses statistical significance (p<0.06). The female subgroups rate the sounds as noisier than the male subgroups with the older female subgroup rating the sounds as the noisiest. Regarding the scale "danger", there is a highly significant main effect of age (p<0.001). The older subgroups rate the sounds as more dangerous than the younger ones. For the scale "sportiness", a main effect of gender is found ($p<0.05$). The female subgroups rate the sounds as more sporty than the male ones. Altogether, the older women display the most critical attitude towards the experimental sounds with highest ratings for “annoyance”, “noisiness”, and “danger” whereas the other three subgroups do not differ that much in their noise evaluations.

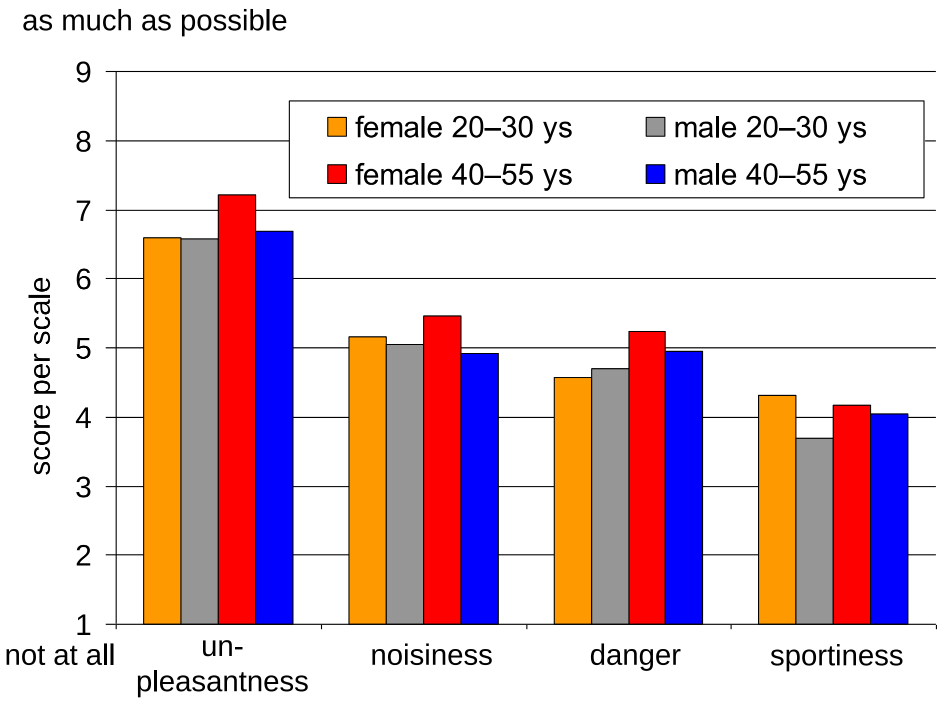



**Figure 5:** Mean scores of the four subgroups in the four scales derived from the adjective list for evaluation of pass-by noises

## Influences of moderating variables on the individual noise effects

For some of the attitudes and personality traits assessed by the questionnaires, the distribution among the four subgroups of this study differs significantly, and some of them also correspond with the subjects’ physiological responses to the pass-by noises.

Here we will only give some results concerning the skin conductance level as an example. In Figure 6, the sample is divided into two groups by median split, and then the mean SCL during sound exposure is compared between the two groups. The green bars represent the half of the sample in which the personality trait in question is represented strongly whereas the grey bars stand for the other half of the sample. The SCL response to the sounds was stronger for people with high noise sensitivity according to the Weinstein scale (Weinstein 1978). Two scales of the “Questionnaire on individual attitudes towards the acoustical environment” (Notbohm 2010) confirm this finding: higher sensitivity and stronger annoyance by noise as well as disliking activation by music is associated with higher SCL reaction. Three of the NEO Five Factor Personality Traits (Costa & McCrae 2006) also yield differences revealing some influences of moderating variables on the skin conductance level: People with higher values regarding neuroticism respond stronger and also people with low extraversion and openness.

Not included in Figure 6 are the results concerning the Sensation Seeking Questionnaire: the group with lower scores showed significantly higher SCL reactions than the other group in the total score as well as in some sub-scores. For the FPA reaction, there were fewer significant differences between the two groups of the median split: Stronger responses correspond with neuroticism, with high values of “agreeableness” and low values of “conscientiousness” from the NEO questionnaire and with “thrill and adventure seeking” from the Sensation Seeking Questionnaire.

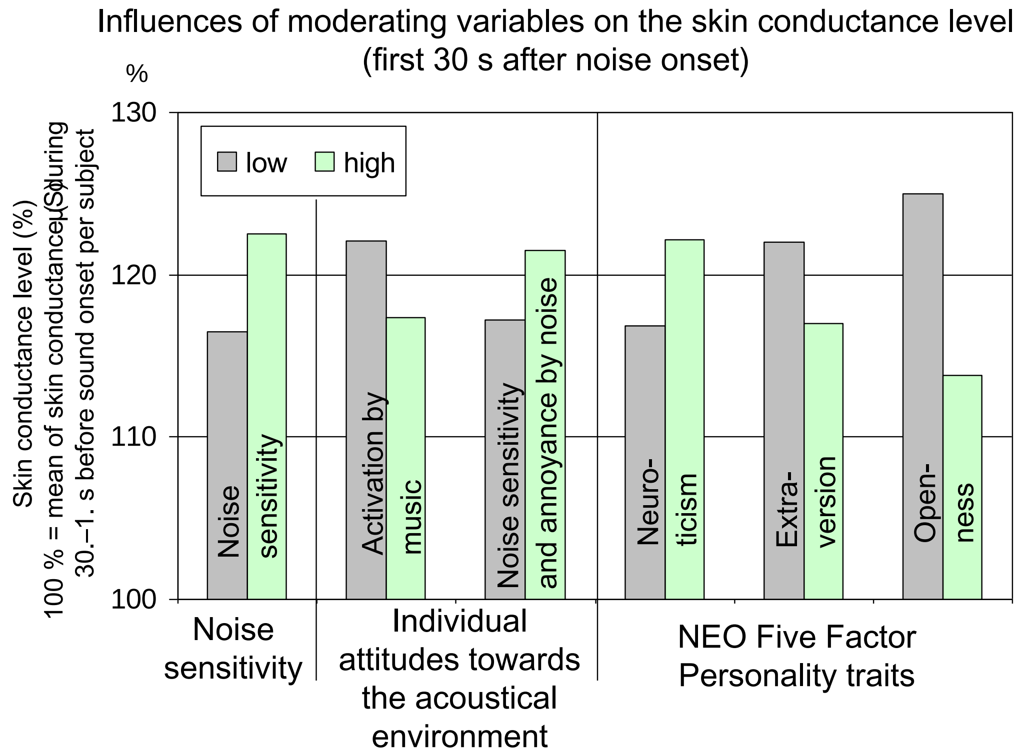



**Figure 6:** Mean levels of SCL-reaction to the noises for the two groups with lower (grey) or higher (green) values after median split for the given questionnaire scales

## DISCUSSION

First of all, the physiological measurements reported above show distinct responses of all four subgroups to the pass-by noises applied. However, there are clear differences between the groups referring to the specific physiological reactions:

- The changes of the skin conductance level during noise exposure reflect exactly the differences between the subgroups with regard to dislike of the noise: The strongest response is found with the older women, followed by the younger women and the two male groups. This fits also well with the very negative judgments especially of the older women in the scales of the adjective list as shown in Figure 5.

- The reaction of the finger-pulse amplitude, however, yields a different pattern of response among the subgroups: Especially the young men show an impressively strong reaction to the stimuli, whereas the female groups respond quite weakly. There is only one corresponding result among the subjective responses, namely the more positive scores of the two male subgroups for the judgment “I like the noise”.

The divergent results for the two physiological measures reported here have to be examined further. One explanation could be that the two physiological systems involved are influenced differently by the factors age and gender, i.e., that the tissue structure or hormonal changes might be largely responsible for the deviating responses of the groups with regard to the vascular responses.

Another intriguing explanation would postulate the existence of two different qualities or levels of reaction linked to the different physiological systems, and at this point the moderating variables get involved. The electro-dermal response corresponds very well to subjective data on the noisiness and the disapproval of the sounds, and the SCL reaction is stronger with noise sensitivity, annoyance by noise, introversion, and lack of openness. On the contrary, the FPA response seems to be connected with quite different traits such as agreeableness or sensation seeking. Of course, these are just some hints based on statistical relations, but they support the hypothesis that there are different patterns of response to environmental stimuli which express different subjective perceptions and stimulate divergent physiological pathways.

With regard to the demographic changes of our societies, the main result of this study seems to be the necessity to consider the differences in the perception of environmental noise not only in relation to age, but also to gender. This aspect of different patterns of response needs to be investigated more thoroughly to improve the understanding of human responses to real environmental noise and to optimize preventive measures.

## ACKNOWLEDGEMENT

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# Road traffic noise, air pollution and blood pressure in Oslo, Norway

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## INTRODUCTION

Epidemiological studies have reported an association between traffic noise and hypertension. Especially with respect to aircraft noise there is increasing evidence for an association with hypertension (Babisch 2006; Eriksson et al. 2007; Jarup et al. 2008). There are indications that also road traffic noise may contribute to hypertension (Babisch 2006; Barregard et al. 2009; Bluhm et al. 2007; Bodin et al. 2009; de Kluizenaar et al. 2007), but these findings are more inconsistent, bearing in mind the possible confounding by traffic-related air pollution. In addition, most of these studies are cross-sectional with self-reported hypertension.

Special attention has been drawn to the possible harmful effect of night-time noise exposure on cardiovascular risk (Griefahn et al. 2008; Jarup et al. 2008), and acute effect of night-time aircraft noise on blood pressure has been observed (Haralabidis et al. 2008). However, very few epidemiological studies have included night-time noise exposure in their analyses.

The aim of the present study was to examine the relationship of road traffic noise with blood pressure and hypertension in an adult population, adjusting for several possible confounders including traffic-related air pollution. Of particular interest was the association between night-time road traffic noise and hypertension.

## METHODS

### Study population and design

The participants (N=21,363) in the population-based “Oslo Health Study” HUBRO (2000-2001) underwent a physical examination including blood pressure measurements. We identified hypertension as measured systolic blood pressure above 140 mmHg, measured diastolic blood pressure above 90 mmHg or self-reported use of antihypertensive medication. The study was approved by the Regional Ethics Committee and the Norwegian Data Inspectorate.

### Environmental exposure assessment

Noise from road traffic was calculated according to the EU directive for noise (European Commision 2002). The noise indicators $L_{den}$ and $L_{night}$ were calculated on 5 x 5 $m^2$ grid, using The Nordic Prediction Method for road traffic noise (Nordic Council of Ministers 1996). The noise levels were calculated for the year 2006, and only those who lived at the same home address in 2000 and 2006 were included in the analyses (N=13,174). The input data on Road traffic (traffic counts, % heavy vehicles, speed limits, diurnal distribution) was obtained from the Norwegian Public Roads Administration and the City of Oslo. Using the geographical coordinates for each participant's home address, all participants were assigned residential road traffic noise at the most exposed façade.

The Nordic prediction method for road traffic noise calculates noise exposure at the most exposed facade with a deviation of ± 3-5 dB depending on the distance from the noise source. "Deviation" denotes the difference between the calculated value and the measured long-term average using standard procedure for noise measurements. Combining the prediction method with a geographical information system is considered the best available method to assess residential noise exposure.

Nitrogen dioxide ($NO_2$) was calculated by the EPISODE dispersion model on 1 $km^2$ grid. Based on historical data on emissions (especially from road traffic), meteorology and background air pollution concentrations, The Norwegian Institute for Air Research has developed a dispersion model which calculates outdoor levels of $NO_2$ (Oftedal et al. 2009). Using geographical coordinates for the home addresses, all participants were assigned $NO_2$ levels. Modeling of long-term averages has recently been evaluated by comparing modeled levels versus measurements from monitoring stations in Oslo, and this model may represent long-term levels of local outdoor air pollution reasonably well (Oftedal et al. 2009).

## RESULTS

The distributions of road traffic noise are presented in Figure 1.

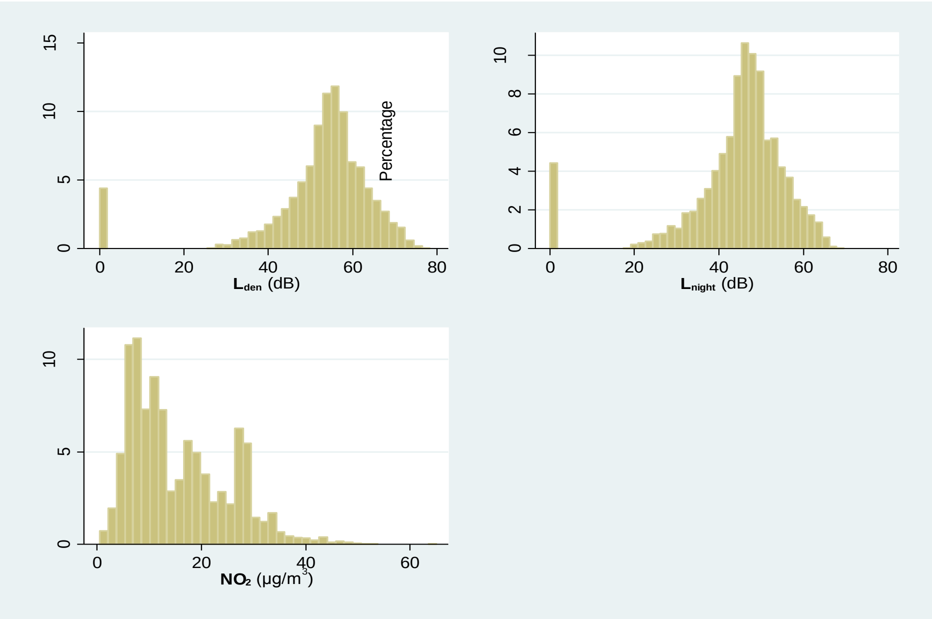


**Figure 1:** Distribution of residential exposure to road traffic noise ($L_{den}$ and $L_{night}$) and to $NO_2$.

Preliminary results showed that road traffic noise ($L_{den}$) ≥ 60 dB was associated with an increase of 0.9 mmHg (95% confidence interval (CI): 0.0, 1.8) in systolic blood pressure compared to noise levels <50 dB, while no associations were found with diastolic blood pressure. The results were similar for $L_{night}$, except for a minor change by adjusting for $NO_2$. Figure 2 shows the estimates for systolic blood pressure in different $L_{night}$ categories adjusted for several potential confounders, of which one of the models includes $NO_2$.

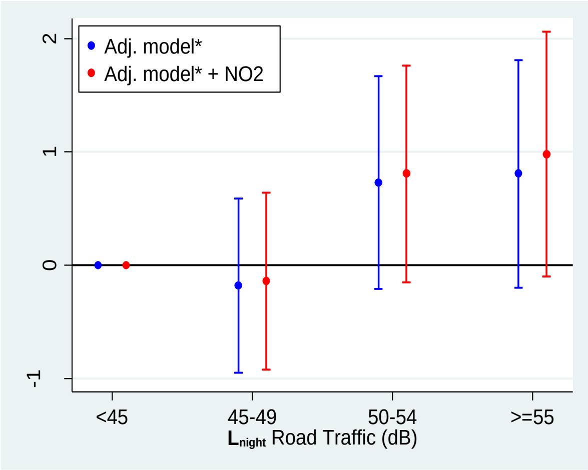


**Figure 2:** Estimates of coefficients with 95% CI for systolic blood pressure for different noise exposure categories, *adjusted for age, sex, smoking habits, intake of fruit, cod liver oil intake, waist-hip ratio, seasons, marital status, education and western country of birth, with $L_{night}$ <45 dB as the reference category.

We found no associations between $NO_2$ and blood pressure. The correlation between road traffic noise and $NO_2$ was moderate ($r$=0.4). Preliminary results regarding hypertension showed that road traffic noise ($L_{night}$) ≥ 55 dB was associated with an odds ratio (OR) of 1.06 for hypertension (95% CI: 0.92-1.22) with noise levels <45 dB as reference adjusted for age, gender, body mass index and education. However, we found no exposure-response relationship. We found no associations between $NO_2$ and hypertension. Adjusting for $NO_2$ did not change the OR of traffic noise. The results stratified by gender are presented in Figure 3. As can be seen in men the estimated ORs increased with increasing noise levels, but were not statistically significant.

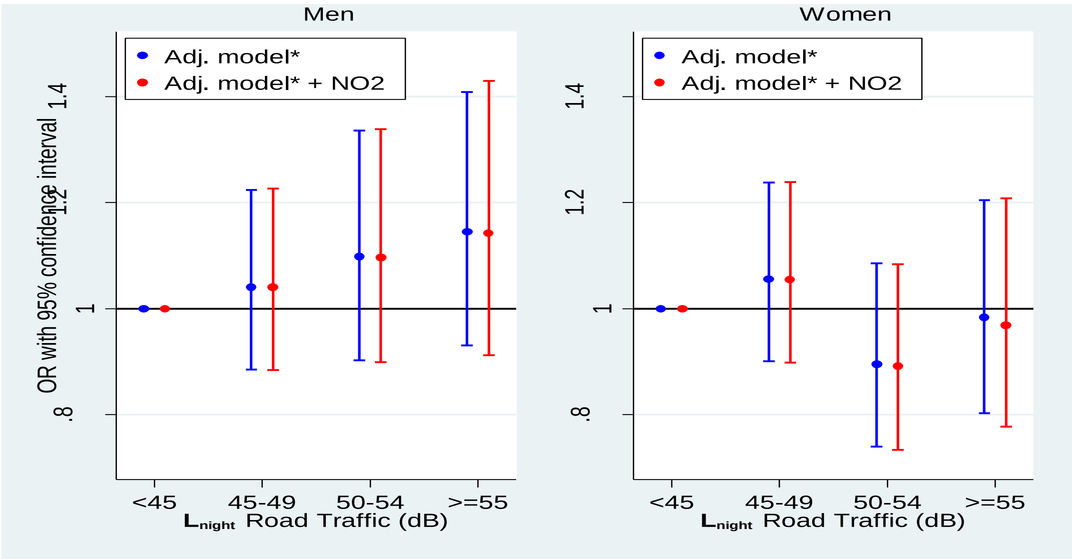


**Figure 3:** Odds ratio with 95% CI for hypertension in men (left) and women (right) for different noise exposure categories, *adjusted for age, body mass index and education, with $L_{night}$ <45 dB as the reference category.

## CONCLUSIONS

Exposure to road traffic noise may be related to a slight increase in systolic blood pressure, and this relationship seemed to be minimally affected by traffic-related air pollution. However, residential road traffic noise was poorly related to hypertension. The association was somewhat stronger in men than women, but did not reach statistical significance. These associations are probably not affected by traffic-related air pollution in Oslo. Further analyses using historic information of changes in buildings, noise screens and traffic data, road traffic noise levels will be calculated backwards to 2000-2001, when the blood pressure measurements were conducted, and will increase the power of the statistical analyses.

In the future, a longitudinal design, including more contextual variables will provide more reliable results on the effect of traffic-related exposures and cardiovascular health outcomes.

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# Noise exposure and serum lipid levels when adjusted for established risk factors

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## INTRODUCTION

Several studies have associated noise exposure with cardiovascular diseases (Melamed et al. 1999; Virtanen & Notkola 2002; Davies et al. 2005; Virkkunen et al. 2005; Gan et al. 2011) but van Kempen and colleagues concluded in a meta-analysis that the relation between noise exposure and ischemic heart disease is inconclusive (van Kempen et al. 2002). Serum lipids play a major role in the causation of cardiovascular diseases and may also be of causal importance for the association between noise exposure and cardiovascular disease (Nabel 2003). There is some empirical evidence that a noise exposure level above 80 dBA increases the level of cholesterol and triglycerides (Ortiz et al. 1974; Rai et al. 1981; Melamed et al. 1997; Vangelova & Deyanov 2007) but this effect has not been reported by others (Chang et al. 2003; Virkkunen et al , 2005, 2006). Serum lipid levels are influenced by sex, age, body mass index (BMI), waist width, statins, beta-blockers, and other medicines, diabetes, smoking, alcohol, physical activity and social status (Stone 1994; Kasiske et al. 1995; Hu et al. 2000; American Heart Association 2002; Virtanen & Notkola 2002; Carroll et al. 2005; Primatesta & Poulter 2006; Gossett et al. 2009), however, only Melamed et al. accounted for such competing risk factors (Melamed et al. 1997).

This study analysed if increasing levels of occupational noise exposure is associated with increasing levels of total cholesterol, low-density lipoprotein (LDL)-cholesterol, triglycerides and decreasing levels of high-density lipoprotein (HDL)-cholesterol when adjusted for well-documented risk factors.

## METHODS

### Subjects

In 2009-2010 we recruited 76 companies from manufacturing industries, construction and children day care with expected high noise exposure levels and finance intermediation as a reference. A total of 544 workers (396 male and 148 female workers) from these companies agreed to record noise levels and provide a blood sample and they comprised the study population. Triglycerides were not measured on 19 workers and therefore they have no estimates of LDL-cholesterol and triglycerides. Further details of recruitment procedures and measurements are described elsewhere (Kock et al. 2004). This cross-sectional study conformed to the Danish legal requirements and was approved by the local ethics committee.

### Noise exposure assessment

Noise exposure levels were measured by portable dosimeters (*Bruel and Kjær 4443*). The dosimeters were calibrated, handed over and collected at the workplaces. The dosimeters were worn in a pouch attached to a belt at the participant's waist. Microphones were placed on the shoulder, right shoulder if right-handed and left shoulder if left-handed. The A-weighted equivalent sound level ($L_{Aeq}$) was recorded every

5 seconds for 24 hours. The dosimeters were set to a dynamic range of 50-120 dB. The display was dimmed during measurements to minimize noise dependent changes in the participant's behavior. On the day of the noise measurement, the participants registered the beginning and ending of working hours, transport time and leisure time, and we estimated the $L_{Aeq}$ values for each of the three time periods.

### Personal data

At the day of examination, we measured height, weight and waist width and calculated the BMI. We also collected a venous blood sample and analyzed the levels of total cholesterol, HDL-cholesterol and triglycerides by a chromogen catalytic method. We estimated LDL-cholesterol from the formula of Friedwald's: LDL-Cholesterol = total cholesterol – HDL-cholesterol – 0,45 x triglycerides (triglycerides < 4,5 mmol/l) (Danish Regions 2009).

### Statistics

We classified participants into three full-shift occupational noise exposure groups: low (< 80 dBA), medium (80-85 dBA) and high (> 85 dBA). Potential confounders were tabulated by increasing noise levels. Lipid levels were normally distributed and arithmetic mean, standard deviation and 95% confidence intervals were tabulated by noise exposure levels. We analyzed serum lipids as a function of occupational noise exposure by linear regression. The models also included sex, age, BMI (<25, 25-35, >35) medicines (statins, beta-blockers, estrogens, retinoids, diuretics, levothyroxin or glucocorticoids; yes/no), diabetes, smoking, alcohol, physical activity, education, income, and noise exposure during leisure and transportation time. Trend test based on grouped and continuous data were performed in crude and adjusted models. Data processing and analysis were performed with STATA version 11 (STATA Corp., College Station, TX).

## RESULTS

The median noise exposure level was 82 dBA (range: 57- 114 dBA). In all, 206 workers were exposed at a low, 198 at a median, and 140 at a high noise level. Increasing noise levels were associated with increasing BMI, waist width, and leisure and transportation time noise levels. Levels of total cholesterol, LDL-cholesterol, triglycerides and cholesterol/HDL ratio increased and HDL-cholesterol level decreased by increasing occupational noise exposure. The latter three findings were of statistical significance ($p<0,05$). However, when we adjusted for BMI no trend remained. Further adjustment by sex, age, medicines, diabetes, smoking, alcohol, physical activity, education, income, leisure time and transportation time noise levels confirmed this finding of no effect.

## DISCUSSION

We observed no association between occupational noise exposure and serum lipid levels when account was taken for well-established risk factors. Thus, we could not confirm earlier suggested findings of such an effect. This discrepancy may be due to insufficient control for documented risk factors in earlier studies. Six studies (Ortiz et al. 1974; Rai et al. 1981; Melamed et al. 1997; Chang et al. 2003; Virkkunen et al. 2005, 2006; Vangelova & Deyanov 2007) have investigated the association between occupational noise exposure and lipid levels but only Melamed et al. adjusted for such risk factors (sex, age, BMI, smoking, alcohol and physical activity). They found a significant association but only for a subpopulation (young men) and not for the total population. Four studies reported statistically significant crude associations between noise exposure and increasing lipid levels, but findings were not consistent across studies with respect to lipids affected (Ortiz et al. 1974; Rai et al. 1981; Melamed et al. 1997; Vangelova & Deyanov 2007). Our findings are, on the other hand, in line with those of Virkunen et al and Chang et al who observed no association between noise exposure level and serum lipid levels(Chang et al. 2003; Virkkunen et al. 2005, 2006).

This study has several strengths. Our extensive adjustment for risk factors has already been mentioned. Environmental noise exposure has also been suggested to affect cardiovascular health (Passchier-Vermeer & Passchier 2000; Babisch et al. 2005; Babisch 2011) and we were able to adjust for such potential confounding. Furthermore, each participant was equipped with personal dosimeters to ensure exact measurements of noise exposure in contradiction to stationary measurements. Selection bias is not expected to have affected findings since it is implausible that workers with high lipid levels and high noise exposure are more prone to enter or leave the noisy work sites recruited for this study. Differential recall is likewise unlikely to have biased findings because we analyzed objective measures of noise and lipids levels.

The study also has limitations. We did not take account of the use of hearing protectors. This might have contributed to the no effect seen since the higher exposed participants are expected to wear protective devices more often, thereby reducing the noise exposure contrast and the ability to detect a true effect of noise if existing. Further studies should account for the use of hearing protectors when assessing exposure at the ears of the individual worker.

To conclude, we observed no significant association between occupational noise exposure and serum lipid levels when adjusted for well-established risk factors. We could thus not support earlier findings suggesting that lipid levels may be of causal importance for the observed association between noise exposure and cardiovascular disease. Future studies should focus on improved exposure assessment at the ear in addition to established risk factors.

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# NORAH – Study on *Noise-Related Annoyance*, Cognition and *Health*: a transportation noise effects monitoring program in Germany

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## INTRODUCTION

Since the announcement in 1998 there have been discussions in the Rhine Main area among stakeholders about the expansion of Frankfurt Airport, including the construction of the 4th runway (opening expected in October 2011), and about the health-related effects of aircraft noise in relation to other noise sources.

In order to get more insight into the effects of transportation noise in general (not only aircraft noise) the state-owned Environment & Community Center (ECC) of the Forum Airport and Region (FFR) commissioned the authors of this contribution to develop and conduct a noise effects monitoring program at Frankfurt Airport and comparative studies at other German airports. The subject matters of this study, called NORAH study (*No*ise-*R*elated *A*nnoyance, cognition and *H*ealth) are

- noise annoyance and health-related quality of life (HQoL; including reported diagnosed health diseases): Aircraft noise annoyance and HQoL before and after the opening of the 4th runway in comparison to annoyance at other airports; compari-

son of HQoL and annoyance due to aircraft, railway and road traffic noise; effects of combined transportation noise exposure on annoyance and HQoL;
- effects of transportation noise on hypertension and cardio-vascular diseases and the causal structure of noise exposure, noise reactions, and health effects;
- effects of changing nocturnal noise exposure at Frankfurt Airport on sleep;
- noise effects on cognitive performance and health-related quality of life (HQoL) in children.

The study started in April 2011 and is initially projected for three years. In this contribution the concept and methods of the monitoring program are presented.

## BACKGROUND AND WORKING MODEL

Environmental noise, particularly transportation noise, is one of the main environmental burdens in modern society. According to the World Health Organization (WHO 2011) the core outcomes of environmental noise in terms of disability-adjusted live years (DALYs) are sleep disturbance, annoyance, cardio-vascular diseases, and cognitive impairment in children.

The health-related effects of long-term exposition to environmental noise are regarded as an example of the distress-inducing impact of environmental burden. According to noise-related stress models (e.g. van Kamp 1990) the above mentioned noise effects are interrelated and can be understood as parts of the distress-inducing process. When imposed demands of an environmental stressor (noise) exceeds the ability of the individual to cope with it this results in acute psychological and physiological strain (Henry & Stephens 1977; Lazarus & Launier 1978). Perceived control, noise annoyance, cognitive impairments, and sleep disturbances going along with physiological reactivity are well-known stress reactions to noise (Westman & Walters 1981). On a long-term level, the chronic imbalance between demands due to noise and coping abilities may trigger the risk of health problems, in particular cardiovascular diseases including hypertension, coronary heart disease, and myocardical infarction (Babisch 2006; Babisch & van Kamp 2009; van Kempen et al. 2002).

The effects of environmental noise are co-determined by personal (e.g. noise sensitivity, age), attitudinal (e.g. attitudes toward the source, misfeasance, perceived fairness of noise management), and situational factors (house insulation, window position length of exposure) (Fields 1993; Guski 1999; Maris 2008). These non-acoustical factors are assumed to affect the perceived control and the ability to cope with noise, and, finally may contribute to further stress-related health effects (Hatfield et al. 2001). The NORAH study aims to improve the understanding of these causal paths. It includes longitudinal elements in terms of prospective panel studies as well as a retrospective case-control study combined with an analysis of insurance data linked with data on transportation noise of previous years.

The impact of noise gets even more complex when a change in noise exposure emerges as it is the case at Frankfurt Airport with regard to the upcoming airport expansion. After the opening of the new runway, the number of operations increases stepwise from current capacity of 83 to 120 flight movements per hour estimated for the year 2020. Besides changes in the number of flyovers, the airport expansion includes the relocation of flight paths and the implementation of active noise control measures (optimized approach and departure procedures) in order to minimize the aversive effects of aircraft noise. It is well known that reactions to changes in noise exposure, in particular noise annoyance, cannot be predicted by exposure-response functions obtained under steady-state conditions (Brown & van Kamp 2009). Often an excess in noise responses relative to those under steady-state conditions is reported (change effect). However, because within the context of the airport expansion multiple changes occur, partly with contradictory effects on noise exposure, it is almost impossible to formulate any hypothesis on the extent of any change effect or adaptation process in noise reactions of residents living in the vicinity of Frankfurt Airport.

Concerning noise effects on children, in several studies noise-related impairments of HQoL and cognitive performance were found (Haines et al. 2001; Hygge et al. 2002; Stansfeld et al. 2005). It is assumed that underlying basic linguistic functions (phonological awareness and working memory) and speech perception are affected by noise, leading to impairments in reading performance (Klatte et al. 2010). In this study, it is intended to follow up on the West-London study (Haines et al. 2001), the RANCH study (Stansfeld et al. 2005; Clark et al. 2006), and the Munich Airport study (Hygge et al. 2002) and to assess the effects of aircraft noise on reading skills, episodic memory, and attention.

In the Munich Airport study it was found that changes in aircraft noise (closing of the old airport Munich-Riem, opening of the new Munich FJ-Strauss Airport) had not only an impact on children's responses to aircraft noise but also on judgments of other not aircraft noise-related aspects of the environmental quality of life (EQoL) (Meis 1998). With regard to HQoL in children, only a few studies exist, with inconsistent findings (e.g. van Kempen et al. 2010; Bullinger et al. 1999). To get more insight into the relationship between transportation (in this study: in particular aircraft) noise exposure, cognitive performance and HQoL as well as EQoL in children, all these possible outcomes of noise will be assessed within the NORAH study.

## METHODS

NORAH includes three main work packages with altogether 11 longitudinal, case-control and cross-sectional sub-studies (see overview in Table 1).

**Table 1:** Work packages and sub-studies of the NORAH study

| WP | Sub-study | | Source (**primary**, secondary) | Study type | N | Year 2011 | Year 2012 | Year 2013 |
|---|---|---|---|---|---|---|---|---|
| WP1 Annoyance & HQoL | 1.1 | Rhine-Main Panel | **air**, road, rail | LS | 7,000 | X | X | X |
| | 1.2 | BBI Panel | **air**, road, rail | LS | 5,000 | | X | X |
| | 1.3 | Steady-state 1 | **air**, road, rail | CSS | 2,500 | | | X |
| | 1.4 | Steady-state 2 | **air**, road, rail | CSS | 2,500 | | | X |
| | 1.5 | Rhine-Main road | air, **road**, rail | CSS | 2,800 | | X | |
| | 1.6 | Rhine-Main rail/road | air, road, **rail** | CSS | 3,200 | | X | |
| | 1.7 | Rhine-Main combi | **air-road; air-rail** | CSS | 2x 1,200 | | X | |
| WP2 Health effects | 2.1 | Second. analys. & case-control | **air, road, rail** | CCS | ~ 2 Mio / 24'000 | | X | |
| | 2.2 | Blood pressure | **air**, road, rail | LS | 2,000 | | X | X |
| | 2.3 | Sleep quality | **air**, road, rail | LS | 40 to ~400 EEG-ECG | EEG | ECG+ Acti | ECG+ Acti |
| WP3 Children | 3.1 | Cognition perform. & HQoL | **air**, road, rail | CSS | 1,000 | | X | |

LS = longitudinal study; CSS = cross-sectional study; CCS= case-control study

### WP1: Annoyance and HQoL

WP1 includes longitudinal and cross-sectional telephone surveys on the effects of transportation noise on annoyance, disturbances and HQoL, in addition with reported diagnosed health diseases and sleep quality. For the address of each participant the source specific exposure to aircraft, railway, and road traffic noise will be calculated on the basis of a detailed acoustic source and propagation model. The study population at each investigated airport includes all residents living within the 40 dB(A) envelope contour of the equivalent sound levels of aircraft noise for day and nighttime.

The main sub-study of WP1 is the **panel survey in the Rhine-Main area** around Frankfurt Airport. It focuses on the effects of aircraft noise before and after the opening of the new runway (Oct. 2011). Residential areas within the study area will be selected with aircraft noise as the predominant noise source and rail and road traffic as secondary sources. Initially, three annually repeated measurements are planned to study the development of noise reactions and possible adaptation to the changes in aircraft noise exposure. The first measurement takes place before the opening of the 4$^{th}$ runway, the second measurement 12 months, and the third measurement 24 months after the opening. A stratified random sampling procedure with aircraft noise exposure ($L_{Aeq}$) as strata will be applied. Based on a power analysis and accounting for drop outs an initial sample size of 7,000 participants is intended for the first measurement. In the following years, the panel sample will be restocked to 5,000 participants for each measurement. This allows controlling for bias effects due to repeated measurements. The questionnaire for the telephone interviews includes questions on annoyance and disturbances due to aircraft, road and railway noise, health-related quality of life, diagnosed health diseases, coping to noise, noise sensitivity, attitudes towards the sources, and authorities, the perceived fairness of the procedure or the air traffic (noise) management, housing condition, insulation, etc., and socio-demographic characteristics.

**Comparative studies will be done at three other airports**. One airport, which is also in a change situation (expansion from a regional airport to an international airport), is Berlin Brandenburg International (BBI) with an expected opening in summer 2012. This airport is chosen for a comparative study in order to replicate temporal trends in noise annoyance or any change-effect in annoyance found at Frankfurt Airport at an airport in another stage of planning and extent of expansion. Two other – not yet nominated – German airports under steady-state condition will be included for further comparison. At BBI Airport two repeated measurements will be done in 2012 and 2013 before and after the opening of the expanded airport (initial sample size: n = 5,000). At the other two airports, cross-sectional surveys will be carried out in 2013 with a sample of about 2,500 participants at each airport.

Whereas in the panel study the focus is on aircraft noise, in the same study area residential zones with either predominant road or railway noise, respectively, will be selected for two **cross-sectional studies on the effects of railway as well as road traffic noise**. The aim of these studies in addition to the panel study is to get source-specific exposition-response curves for annoyance and disturbances for all three modes of transportation. Altogether 6,800 participants are targeted for both cross-sectional studies on railway and road traffic noise. The last sub-study in WP1 is on the **effects of combined noise from different transportation noise sources** (aircraft combined with either railway or road traffic noise). For this, the data of the previous mentioned sub-studies in the Rhine-Main area will be supplemented by data from areas of the same study region, where residents are exposed to two noise sources (air/road, air/railway) of similar noise levels. That is, altogether, the effects of combined noise will be analyzed against variations of the dominance and noise level of the different transportation noise sources.

In all sub-surveys adapted versions of the questionnaire for the Rhine-Main panel survey will be used.

**WP2 Health effects**

WP2 studies health effects of transportation noise in more detail and includes an analysis of health insurance data of residents in the study area around Frankfurt Airport combined with a case-control study, a longitudinal study about effects of aircraft noise on blood pressure, and a longitudinal study about effects of nocturnal aircraft noise on sleep.

For the **analysis of health insurance data** (‘claims data’) of residents in the Rhine-Main area, data from statutory and private health insurance funds about ambulant and inpatient diagnoses of diseases as well as drug prescribing will be linked with address-related exposure to noise from aircraft, railway, and road traffic. It is expected, that claims data of about 2 Million insurants will be available for the period from 2000 to 2008/2009. The analysis will focus on identifying the relative risk of cardio-vascular health diseases, cancer, and depression for aircraft, railway, and road traffic noise. This analysis concept bases on a similar method used by Greiser and colleagues in the Cologne-Bonn Airport study (Greiser et al. 2007; Greiser & Greiser 2010). In this study the authors estimated the relative risk for health effects of aircraft noise in logistic regression models adjusted for road and railway noise exposure and several demographical and socio-economic confounders on an individual and aggregate level. Greiser and colleagues reported an association between nocturnal aircraft noise levels and cardio-vascular diseases, stroke and, for women, depression. However, information about confounders particularly important for cardio-vascular diseases, such as tobacco consumption, cholesterol level, blood pressure, physical training, body mass index (BMI), and diabetes was not available in the Cologne-Bonn Airport study due to using claims data alone. NORAH WP2 will **combine the analysis of insurance data with an analytic case-control study** focusing on myocardial infarction, cardiac insufficiency, and stroke. Incident cases and a control group without known cardio-vascular disease will be defined on the base of the insurance data. Power analyses revealed that for each disease entity 6,000 persons have to be investigated. Altogether, a minimum of 24,000 insurants (3x 6,000 cases, 1x 6,000 insurants for control) have to participate in the case-control study. The insurance companies will be asked to send questionnaires to the insurants identified as cases and controls. The questionnaire includes questions on social status, tobacco and alcohol consumption, BMI, history of residential living and occupation (last 10 years), life style, stress and life events, house insulation, sleep quality, HQoL, mental health, noise annoyance and sensibility, and attitudes towards the airport. For each insurant (either participants or non-participants of the additional case-control study) current as well as past address-related source specific exposure to aircraft, railway, road traffic noise will be calculated. A non-responder analysis will be performed in addition to the main analyses.

In addition to the secondary data analysis combined with the case-control study, long-term effects of aircraft noise on average blood pressure will be assessed by means of a **blood pressure monitoring**. 2,000 participants (about 400 of them also take part in a study on sleep quality, see below) will be trained to assess their blood pressure in the morning and evening on 14 consecutive days in 2012. In addition, they fill in a questionnaire on HQoL and cardio-vascular risk factors. The same participants would repeat this measurement one year later in 2013. The 2,000 participants will be recruited as a sub-sample from the Rhine-Main panel sample of WP1.

The method of self-administered measurement of blood pressure was already used in a time-series study by Aydin & Kaltenbach (2007), carried out with 53 residents living in the vicinity of Frankfurt Airport. The authors found, firstly, that the self-administered measurement of blood pressure provides reliable data and, secondly, that the average blood pressure was associated with changes in aircraft noise due to the alteration of east/west mode of flight operation. In this sub-study of WP2 the aim is to analyze, whether blood pressure averaged over all measurements within one 14-day-period as well as the risk of cardio-vascular diseases in total is associated with aircraft noise exposure, road traffic and railway noise and whether the changes in the flight operations due to the airport expansion correspond with changes in the average blood pressure over time.

**The effects of nocturnal aircraft noise on sleep at Frankfurt Airport**, in particular aircraft noise-induced awakenings, will be assessed physiologically and by means of questionnaires within a longitudinal study with repeated measurements in 2011, 2012, and 2013. For this, the methods used in the study on the effects of nocturnal aircraft noise by the German Aerospace Center (DLR; Basner et al. 2004) will be adopted. The aim of this sub-study in WP2 is to monitor potential changes in the probability of awakening against the maximum sound level of nocturnal flyovers before and after the opening of the new runway. According to agreements between the airport and communities and the official approval of the expansion plan, it is expected that the number of night flights will be reduced if not banned between 11 p.m. and 5 a.m. after the opening of the 4$^{th}$ runway. As the total number of flights between 10 p.m. and 6 a.m. (German night period) will amount to about 150 movements (current agreement), the operation constraints between 11 p.m. and 5 a.m. implies an increase in flight movements in the evening and morning shoulder hours. It is expected that these operational changes will lead to an increase in awakenings and problems to fall asleep in the second round (first measurement after the runway opening). The purpose of the third measurement, 24 months after the opening of the new runway, is to find out whether residents in the long run will habituate to the new situation. A power analysis showed that polysomnographical measurements (PSG) of awakenings with 40 persons (minimum: 35) on several consecutive nights following a habituation night would be sufficient to establish an exposure-response curve for the probability of aircraft noise-induced awakenings. According to a re-analysis of laboratory data of the Nocturnal Aircraft Noise Effect study of DLR, there is evidence that EEG awakenings assessed with invasive and sumptuous PSG correspond with automatically detected cardiac activations (ECG), which is a non-invasive cheaper method compared to the PSG (Basner et al. 2008). However, it is still unclear whether the developed ECG-based algorithm for the automatic identification of cardiac activation is suitable for the study of noise effects on sleep in the field. Nevertheless, it is assumed that combining the ECG measurements with actigraphy for the measurement of body movements during sleep allows to reliably predict noise-induced EEG awakenings. This will be tested in the first measurement with 40 participants living in the vicinity of Frankfurt Airport. If the combination of ECG and actigraphy turns out to be a reliable and sensitive method for the assessment of noise-induced awakenings, the study would continue with this method to estimate the effects of aircraft noise on sleep of about 200 to 400 participants in the second and third measurements. For each participant the nocturnal aircraft noise events will be measured and recorded at the ear of the sleeping person. As it is the case for the participants of the blood pressure monitoring the participants of the sleep study will be recruited as a sub-sample from the Rhine-Main panel sample of WP1.

**WP3 Noise effects on children**

Following the study design of the RANCH study the children in the NORAH study will be sampled via primary schools within the Rhine-Main study region. A stratified random sampling procedure will be used to select the schools. Stratum is the aircraft noise exposure of the schools indicated by the equivalent sound level for daytime (five noise level classes between 40 and about 65 dB(A)). It is intended to draw a sample of about 1,000 pupils from 50 classes of 25 schools. The measurements will take place as group tests in the schools. They will include a reading test and, tests of non-verbal intelligence, verbal long-term memory, phonological processing, speech perception, and attention. In addition, the children fill in questionnaires on noise annoyance, perceived EQoL and HQoL, and on the social climate in the school class. A questionnaire, filled in by the parents, includes questions on the child's life situation and circumstances (school achievement, health, developmental disorders) and the assessment of the child's HQoL. Confounding factors such as socio-economic status and teaching methods are assessed via parents and teacher questionnaires. For the address of each school and the home address of each pupil the exposure to aircraft, road traffic, and railway noise (schools: $L_{day}$ inside and outside; home: $L_{day}$, $L_{night}$ outside only) will be calculated.

## CONCLUSIONS

The NORAH study, a 3-years-monitoring program on transportation noise in the vicinity of Frankfurt Airport and – for comparison – at three other German Airports, started in April 2011. NORAH includes three work packages on noise annoyance, HQoL, cardio-vascular health diseases (including hypertension) of adults, and cognition and HQoL in children. As Frankfurt Airport is in a change situation (opening of a new runway, implementation of several measures of active noise control) the specific aim of NORAH is to study the aircraft noise effects over time (in relation to the effects of noise from road and railway noise) under change condition.

NORAH includes cross-sectional, case-control and longitudinal sub-studies with a wide range of methods for the assessment of the transportation noise effects in adults and children: Interviews, psychological tests, physiological measurements, and secondary data analysis combined with a case-control study. An interdisciplinary team including scientists of acoustics, environmental and social medicine, epidemiology, physics, psychology, and sociology has been formed to carry out this noise effect monitoring program.

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# Reliability and validity of instruments to measure pre-school children's reaction to and coping with noise

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## SUMMARY

Population surveys in Sweden indicate that noise in general and noise inside or around schools in particular is a main source of disturbance among children. The noise levels at schools and preschools are high. Since Swedish preschool children (aged 1,5 – 6 yrs) spend most of their waking time at preschools, the amount of daily exposure is also high. Very little is known about how young children are affected by and how they cope with noise. In order to better understand young children's reactions, a study was performed among preschool children. This study consisted of a qualitative and quantitative part, the latter including a before and after measurement. Results of the qualitative study gave insight into how children describe their sound environment and how they emotionally respond to it. Based on that, a questionnaire was developed, about bodily and emotional reactions of young children to noise. The questionnaire was used in an intervention study before and after acoustical interventions at seven preschools. In the before condition 61 children aged 4-6 years were interviewed and in the after condition 59. This paper summarizes the results of psychometric analysis on these materials and describes the reliability and validity of instruments to measure reaction to noise and coping in children aged 4-6 years.

## INTRODUCTION

Reactions to and coping with environmental noise have been studied extensively in the past 30-40 years. While adult reactions to noise have been well-documented and several recent studies addressed annoyance and coping in school children, only a handful of studies dealt with this issue in younger (preschool) children. Studies in adults and schoolchildren have primarily focused on traffic related outdoor noise exposure, while daycare centre exposures primarily relate to sounds of the children themselves (van den Berg 2010). In comparison with adults, children in general and preschool children in specific may be particularly susceptible to the effects of noise, because they have less capacities to anticipate, understand and cope with stressors (Bistrup 2003) and because they are in a crucial and sensitive phase of their development (WHO 2000; Stansfeld et al. 2005). Noisy preschool environments could e.g. lead to reduced understanding of speech and as a consequence impaired reading and writing abilities (Maxwell & Evans 2000). Exposures at a young age might also effect other aspects of later life functioning and the development of disease. Effects described in the literature that indicate such a mechanism pertain to increased levels of cortisol in children attending day care centers (Dettling et al. 2000; Evans 2004; Blair et al. 2005). Studies in older children have confirmed sleep disturbance in relation to chronic noise exposure (Öhrström et al. 2006), detrimental effects on reading comprehension and memory (Stansfeld et al. 2005), performance (Haines et al. 2003), coping, wellbeing and stress (Lercher 2003; May et al. 2009), as well as behavior and mental health (Stansfeld 2009), in particular ADHD. Literature on noise at preschool and daycare centers is primarily focused on room acoustics, effects on teachers and community reaction to children's sounds when playing outdoors (van den Berg 2010). The effects of the indoor sound quality on children was seldom a topic of study and instruments to investigate young children's reactions to noise are not available. Instruments that are suitable for this age group such as the KINDL (Ravens-Sieberer & Bullinger 1998), rather measure quality of life and wellbeing. It is uncertain whether (very) young children are capable to answer questions during a structured interview regarding their sound environment and the way they emotionally and physically respond to it in a consistent way. It is also not clear whether they are able to distinguish between emotions, bodily reactions, coping and symptoms in the way older children and adults can. Data from the before and after interviews of the Mölndal study in Sweden were used to study the validity and internal consistency of the questionnaires which were employed.

**Objectives**

This paper summarizes the validation of set of questions developed on the base of focus group interviews among 4-6 year old preschool children (Dellve et al. 2011). Questions pertain to preschool children's perception to noise when at school, their bodily and emotional reaction to it, non specific (stress related) symptoms and their coping strategies used to diminish detrimental effects of the noise.

**Noise sources**

Dominant noise sources in preschools are sounds from children's activities indoors. The levels are influenced by the number of children per group/room, room acoustics and also, to some extent, other indoor and outdoor factors such as noise from ventilation and traffic related sources, as well as aspects such as pedagogical methods and noise awareness (Dellve et al. 2011). Voss (2010) measured average levels around 80 $Lp_{Aeq8h}$ dB in nurseries and kindergartens in Denmark. Maxwell and Evans (2000) report average levels of 76 $Lp_{Aeq4h}$ dB and average maximum levels of 96 $Lp_{AFmax4h}$ dB before acoustic interventions. Also elsewhere average levels of 80 $Lp_{Aeq8h}$ dB in daycare centres have been reported (van den Berg 2010)

METHODS

**Selection and recruitment**

Children aged 4-6 years and their parents were recruited from seven preschools in the municipality of Mölndal, located at the west coast of Sweden. Before the intervention, 61 children and 59 parents filled out the questionnaire and after the intervention 59 children and 49 parents took part. A control group of 24 and 26 parents from three preschools with no interventions was also included in the study. Due to external circumstances no children were selected for the control group from preschools, where no intervention took place. The response rates ranged from 80 % in the parents to 98 % in the children.

**Procedure**

The children's questionnaires were completed by two trained interviewers based on a structured interview. The children were asked questions in a structural way and presented with visual representations of scales. When the child was not able to answer the question they were not prompted to do so. The interviews were performed one month before the intervention and three months after.

## Noise exposure assessment and interventions

Acoustic interventions included the change in floor materials, felt cushions under chairs, and sound absorbing tiles on ceilings and walls. Noise was measured using stationary measurements and personal dosimeters worn by personnel and children in ten preschools (Persson Waye et al. 2009, 2010). The results of the stationary measurements calculated to relate to activity time are shown in Table 1.

**Table 1:** Equivalent noise levels (dBA) corresponding to activity time for the various measured rooms.

| Room | LpAeq | | Difference (95% CI) |
|---|---|---|---|
| | Before | After | |
| Eating room | 69 | 68 | 1.2 (0,6-1,8) |
| Playhall | 69 | 66 | 3.75 (-0,8-7,6) |
| Playroom | 72 | 69 | 2.9 (1,3-4,5) |
| Eating room* | 68 | 68 | 0.04 (-2,1-2,2) |
| Playhall* | 67 | 67 | 0.30 (-2,7-3,4) |

* Control preschools

Levels from personal dosimeters worn by the children showed higher values or in the range of 85 $Lp_{Aeq}$ dB, and 118 $Lp_{AFmax}$ dB, both before and after the intervention.

## Noise perception

Children were asked how frequently they heard noise from three relevant noise sources: screaming and angry children, strong and loud sounds and scraping and squeaking sounds. Answers were indicated on a five -point Likert scale (ranging from ‘never to very often’) presented as 5 circles increasing in size and including 1-5 dots. For the children, this set of questions was asked for the preschool situation only. If the children indicated that they never heard the noise, reaction was recoded into the neutral representation.

## Reaction to noise

Aspects of reaction were measured by a bipolar visual scale representing drawn figures with different expressions, ranging from happy/safe to unhappy/scared and from kind/friendly to angry/irritated respectively.

## Coping

Coping strategies were investigated by asking the children what they did when there was a lot of noise and if so, how often. The question was asked for noise in general. For each coping strategy they were instructed to indicate how often they would do that, with answers ranging from never to always. Again visual representations were used to measure the number of times they “went away”, “covered their ears” or “told the teacher”. In addition a question was asked about the need to raise their voice in order to be heard.

### Bodily reactions to noise and non specific physical symptoms

In order to measure bodily reactions to the three different noise sources, the children were asked to indicate per noise source whether they could feel the sounds in their body and if so where they felt it. The answers were recoded into location [head] [neck] [arms] [heart] [belly] [legs] [feet] [everywhere] and a [combination of locations].

Non specific physical symptoms were inventoried by asking the children what symptoms they had experienced in the past few days at preschool: headache, belly aches and a hoarse voice, and a general feeling not well.

### Data analysis

In order to test the convergent and divergent validity of the different a-priori indices, principal component analysis (PCA) was carried out using SPSS for Windows (version 18) on the reaction questions, coping and symptom questions. Health symptoms were included, in order to determine whether children could distinguish between emotional responses and non specific symptoms/health complaints. Finally the items on coping strategies were included in the analysis. A high correlation was expected between reactions (emotional) to different noise sources, between symptoms and between the frequencies of use of different coping strategies. In PCA, linear combinations of observations are sought for. Only components that accounted for variances greater than 1 were included. In order to create interpretable components, Varimax rotation was performed. Next, Cronbach's alphas were calculated on the grouped items to test the internal consistency of the obtained components. This process was done for the before and after measures. Finally, the association between these factors and questions about bodily sensations and parental observations of the child’s physical condition were used to explore the external validity of the measures. This was done making use of an ANOVA test as well as by calculating simple correlations.

A more detailed description of methods and results, including a before after comparison, will be published elsewhere.

## RESULTS

### Participants

Respectively 61 and 59 children participated in the study, with an almost 50/50 boy girl ratio and an age range between 4-6 years old. The number of children per preschool ranged from 4-15.

### Emotional reaction to noise in children: construct validity

In the PCA on emotional reactions per source, symptoms and coping behavior respectively a four and five components solutions was found, explaining 59/63 % of the variance in the before measurements. In the before condition the first component consists of items referring to symptoms. The second component consists of items regarding coping strategies children employ when bothered by noise. The items forming the third and fourth component refer to reaction to noise in terms of sadness and reaction in terms of anger. Confirmative analysis in the second measurement (after the intervention) shows a similar pattern, but in this case a three component solution yields a better fit. In this structure, coping and symptoms show the same pattern, but the emotional reactions to noise are grouped around anger; the questions along the sad/happy dimension did not show high interrelations as they did in the first measurement. Results are summarized in Table 2.

### Internal consistency

Based on the factor analysis, respectively four and three indices were tested on their internal consistency expressed in alpha (Table 3). The analysis yielded indices with reasonable internal consistency. An exception is the wellbeing item which loaded on two factors (before) and did not reach the required items-total association of at least .25 (after). Therefore this item was dropped from the scale and included in further analysis as a separate dimension. The same strategy was used for sad reactions to scraping noise in both the before and after condition.

### Index construction

Respectively four and three indices were composed by simply summing up the scores on the individual items, and subsequently the distribution of the scores was tested on normality. Deviations of normality showed to be slight and were, as to be expected, most pronounced in the symptom scales.

**Table 2:** Factor analysis before and after

| | Components/Before | | | | Components/After | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 |
| source1_sad | | | | .80 | | | <.30> |
| source2_sad | | | | .84 | | .59 | <.29> |
| source3_sad | | .44 | | <.29> | | | .62 |
| source1_angry | | | .86 | | | .52 | |
| source2_angry | | | .63 | | | .49 | |
| source3_angry | | | .62 | | | .84 | |
| go away | | .80 | | | .57 | | |
| cover ears | | .71 | | | .67 | | |
| tell teacher | | .63 | | | .46 | | |
| raise voice | | .61 | | | .62 | | |
| headache | .60 | | .49 | | | | .64 |
| belly ache | .68 | | | | | | .80 |
| hoarse voice | .80 | | | | | | .23 |
| unwell-being | .66 | | .40 | | | | .24 |

**Table 3:** Factor name, explained variance, internal consistency before/after *****all sources

| Factor | Interpretation | % Expl. variance | Alpha | Factor | Interpretation | % Expl. variance | Alpha |
|---|---|---|---|---|---|---|---|
| I | Reaction Sad* | 16.1 | .61 | I | n.a. | n.a. | n.a. |
| II | Reaction Angry* | 16.0 | .63 | II | Reaction Angry* | 17.5 | .56 |
| II | Symptoms | 14.6 | .75 | II | Symptoms | 13.2 | .51 |
| III | Coping | 10.8 | .67 | III | Coping | 18.9 | .68 |
| Total | | **57.6** | | Total | | **49.7** | |

## External validity

In the last step the associations between the thus formed indices and bodily reactions to noise and parental evaluations of the child's health were analysed to explore the external validity.

First, the association between bodily reactions to noise with emotional reactions, symptoms and coping were studied. Hereby groups were formed based on respectively *any* bodily reaction versus none, and bodily reactions *per noise source*. (Table 4 and 5; only significant associations are presented).

**Table 4:** ANOVA Bodily reaction and child' s reaction, coping and symptoms *Before

| Tested groups | Against components | F-value | sign |
|---|---|---|---|
| Any bodily reaction | Symptoms before | 9.7 | .003 |
| Bodily reaction to Source 1* | Symptoms before | 5.6 | .02 |
| Bodily reaction to Source 2 | Symptoms before | 4.4 | .04 |
| Bodily reaction to Source3 | Sad reaction before (source 3) | 3.9 | .05 |
| Bodily reaction to Source3 | Symptoms before | 5.8 | .02 |

* source_1: screaming; source_2: loud noise; sound_3: scratching and scraping

**Table 5:** ANOVA Bodily reaction and emotional reaction, coping and symptoms *After

| Tested groups | Against components | F-value | sign |
|---|---|---|---|
| Any bodily reaction | Symptoms after | 3.9 | .05 |
| Bodily reaction to Source 3* | Sad reaction after (source 3) | 3.6 | .06 |

Parental evaluation of their child's health included general health (health, headache, stomach ache, and cold), questions concerning hoarse voice (two questions) and fatigue related questions (five questions). The factor structure showed to be stable over measurements and high internal consistencies were found. The associations between before- and after measurements are consistent, except for hoarseness. This is potentially indicative of a season effect. Symptoms reported by children were highly associated with the fatigue index (r=.41) in the before condition. ANOVA yielded significant differences in means on fatigue for bodily reactions; any location (F=5.7, p=.021) as well as bodily reaction to scraping sounds (F=6.9, p=.011). In the after condition this pattern is only partly confirmed with no association of fatigue with symptoms, but a significant relation between fatigue (reported by parent) and bodily reactions scraping sounds (F=4.9, p=.03). Remarkable is the finding that ear and throat infection, as reported by the parent, is significantly related to bodily reactions of children, both for *any location* (F=6.9, p=.012) and reaction to loud noise (F=6.1, p=.018). These findings are promising with regard to the (external) validity of the preschool questionnaire.

## CONCLUSIONS AND DISCUSSION

### Measurement of reaction in children

The results show that preschool children can make a distinction between emotional and bodily reaction, symptoms and coping strategies as measured by means of representations of reactions, symptoms and behavior. As in adults (van Kamp 2001), the correlation found between different reactions to noise was high, while lower for symptoms and coping. This is consistent with the findings among school children (9-11 yrs) in the RANCH study (van Kempen et al. 2009) and a survey among 207 children (aged 13-14 yrs) of Enmarker & Boman (2004). Furthermore, the results are in agreement with the results of a RANCH sub-study (Gunnarsson et al. 2003) in which children showed to be capable to reliably scale complex *soundscapes* and to provide perceptual scales that were in striking agreement with the perceptual scales provided by adults. We also found that, at least in the before situation, children make a distinction between sadness and anger.

A comparison between before and after data shows a consistent pattern for symptoms and coping, but somewhat less for emotional reactions. At a later stage pair wise comparison by means of ROC[1] analysis will be performed to study the before after associations in more depth. Explorative comparison of children’s symptom report and bodily reactions as well as comparison with parental evaluations of their child’s health reveal a reasonable consistent pattern and indicate satisfactory external validity of at least some of the indices.

### Study strengths and limitations

Strong points of the study are that the questions posed to the children were based on focus group discussion and worded in their own “language”. A major limitation is the relatively small sample size.

### Applicability of the results Implications

The WHO guidelines (2000) for noise suggest that children are more sensitive to noise than adults because they are exposed to noise during critical developmental periods. Children may also have fewer possibilities for controlling noise or have a less developed coping repertoire than adults (Bistrup 2003). Furthermore, this study shows that reaction is not the only relevant indicator of the effects of community noise in children.

### Conclusions

Young children’s reaction to and coping with noise can be reliably measured with a structured interview, including visual representation questionnaires. More work will need to be done to develop a standard to be used in preschool aged children.

[1] ROC or simply ROC curve, is a graphical plot of the sensitivity, or true positive rate, vs. false positive rate (1 − specificity or 1 − true negative rate), for a binary classifier system as its discrimination threshold is varied.

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# Occupational noise exposure and the risk of stroke

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## INTRODUCTION

Community noise exposure about 60 dBA has recently been associated with stroke (Beelen et al. 2009; Huss et al. 2010; Sorensen et al. 2011; Fujino et al. 2007). We aimed at investigating this relation for 81-86 dBA occupational noise exposure and report the incidence of stroke in a large 7-year follow-up study of employees from several noise exposed industries.

## METHODS

We followed 113,141 industrial employees from 625 companies within 10 industrial trades (construction, manufacturers of food, wood products, non-metallic mineral products, basic metals, fabricated metals, machinery, motor vehicles, furniture, publishing and printing) and 47,686 employees in 100 companies from financial intermediation (reference) from 2001 to 2007. The companies were identified from Statistics Denmark (Statistics Denmark 1989) and the employees by linkage with the Register of the Danish Supplementary Pension Fund that for all wage earners in Denmark contains information on employment and trade annually since 1964, and thus also duration of employment (Kenborg et al. 2010; Olsen & Jensen 1987). We identified occupational titles, defined by the International Standard Classification of Occupations (ISCO-88) by linkage with Statistics Denmark (ILO 1990) and retrieved information on socioeconomic status from the Integrated Database for Labour Marked Research (IDA 1988). Vital status (emigration, disappearance or death) was retrieved from the Central Population Register.

We identified cases of stroke (n = 921, defined by the first primary diagnosis of stroke (International Classification of diseases (ICD), revision 8 codes 4310, 4319, 4320, 4329, 43309, 43399, 43409, 43499, 4360, and 4369 and ICD revision 10 codes DI61, DI63, and DI164) recorded between January 1, 2001 and December 31, 2007 in the Danish National Hospital Register, which covers all hospital contacts in Denmark (inpatient hospitalization and outpatient visits).

Full-shift noise exposure levels were estimated by personal dosimeter recordings from random subsets of employees (n = 710) sampled within each of the 10 industrial trades and the one reference trade in 2001 and ranged from 81.5 dBA to 85.8 dBA for the industrial employees and 69.7 dBA for the reference employees (Kock et al. 2004). The trade-mean noise exposure levels classified the individual employee's noise exposure year by year accounting for shift in employment over time between trades and occupations with different noise exposure levels. Individual noise exposures were analyzed by different approaches: (1) Current noise exposure was the trade-mean noise level ($L_{AEq}$ in dBA). This level was set at the reference level (financial intermediation) if the person no longer was employed in a relevant industrial trade or occupation. (2) Cumulative noise exposure was the product of trade-mean noise exposure level ($L_{AEq}$ in dBA) and duration of exposed employment (T) since 1964, according to the following formula: $10 \times \log [\Sigma(10^{dBA/10} \times T)]$ resulting in “dBA-year” on a logarithmic scale.

Rate ratios (RR) and 95% confidence intervals (CIs) for stroke were estimated by logistic regression. The analyses were performed as a discrete survival function, since person year was the unit of analysis. Models were adjusted for age, gender, socioeconomic status, calendar year, hypertension, and employment status (gainful employment: yes/no). We analyzed all data with financial employees as the reference. Because of possible life-style or other differences between the industrial and financial employees not captured in the adjusted analyses internal trend analyses restricted to the noise-exposed employees of the 10 noisy trades were also conducted.

## RESULTS

Industrial employees were more often men, were slightly younger, and had lower socioeconomic status, and shorter duration of employment than the financial employees. Industrial employees showed an overall increased risk of stroke compared with financial employees (adjusted RR = 1.30, 95% CI = 1.07-1.59).

Figure 1 presents the rate ratios for stroke by current noise exposure with financial employees as the reference. RR-estimates of stroke decreased by increasing noise exposure, and there was thus no indication of a positive exposure response relationship. The risk of stroke for non-noise exposed industrial employees was significantly higher than the reference group (adjusted RR = 1.42, 95% CI = 1.07-1.89). This was as expected because a high fraction of them were retired or otherwise without employment. Similarly results were found for cumulative noise exposure.

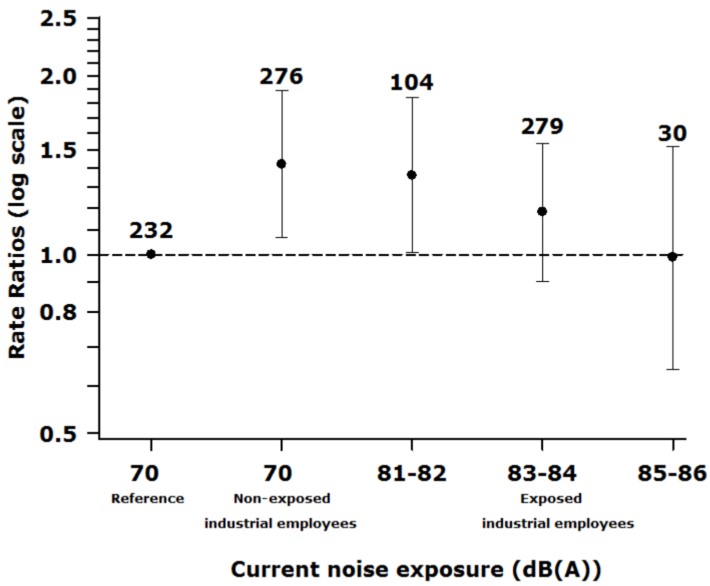


**Figure 1:** Current noise exposure and adjusted rate ratios of stroke among employees of industrial trades (≥81 dBA) compared with employees of the financial sector (70 dBA, reference). Numbers of cases are represented above the bars.

## CONCLUSION

This study had several strengths, including the large sample size, longitudinal design with a long follow up, direct noise exposure measurements in a selected subsample, and the unique database resources for defining and identifying incident cases. However, there were also limitations such as no available individual information on the use of hearing protection devices or several relevant potential confounders such as smoking, body mass index, physical activity or alcohol consumption.

This study did not relate neither current nor cumulative occupational noise exposure with stroke. We could thus not support resent findings of such an effect for community noise. Differences in life style and social factors may explain the overall higher rate among industrial employees compared with financial employees.

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# Long-term exposure to traffic noise and traffic-related air pollution and coronary heart disease mortality

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## ABSTRACT

The authors investigated the independent and joint effects of urban noise and traffic-related air pollution on the risk of coronary heart disease (CHD) mortality. This population-based cohort study included a 5-year exposure period and a 4-year follow-up period. All residents aged 45-85 years who resided in metropolitan Vancouver during the exposure period and without known CHD at baseline were included (n = 445,868). Individual exposures to noise and traffic-related air pollutants (NO, NO2, black carbon, PM2.5) were estimated at subjects' residences using a detailed noise prediction model and land use regression models, respectively. CHD deaths were identified from provincial death registration database. After adjusting for covariates and coexistent traffic-related air pollutants or noise, an interquartile-range (IQR) increase in residential noise was associated with 6 % (95 % CI: 1-11 %) increase in CHD mortality (IQR increase in black carbon, 4%; 95%-CI: 1 - 8%). Subjects in the highest noise decile had a 22 % (95% CI: 4-43 %) increase in CHD mortality compared with those in the lowest decile. Co-exposure to higher levels of traffic noise and black carbon was associated with a substantially greater risk of coronary mortality; relative risk for CHD in top decile of noise and top quartile of black carbon was 1.45 (95 %-CI 1.14 -1.85). These results suggest independent effects of noise and traffic-related air pollution on CHD mortality.

## INTRODUCTION

In recent decades, both air pollution and noise pollution have been associated with increased cardiovascular disease. In metropolitan areas, road traffic is a major contributor to ambient air pollution, and is the dominant source for community noise (Babisch 2008; Brook et al. 2010). Therefore, a concern in epidemiologic studies is that the observed associations between air pollution and adverse cardiovascular outcomes may be confounded by community noise, or vice versa; further, these coexistent environmental pollutants may interact with each other in modifying risks of coronary mortality.

In a previous study, we found that living close to major roads was associated with a 29 % (95% CI: 18-41 %) increase in CHD mortality (Gan et al. 2010). We found that black carbon, an indicator of traffic-related fine particulate air pollution, was associated with a 6 % (95% CI: 3-9 %) increase in coronary mortality, but no robust associations were found for $PM_{2.5}$, $NO_2$ or NO. These findings suggest that exposure to the traffic-related air pollutants alone cannot fully explain the excess risk of coronary mortality associated with residential proximity to road traffic; traffic noise might also play a role in the observed association.

In the present study, we investigated the relations between long-term exposure to community noise and CHD mortality as well as the independent and joint effects of community noise and air pollution (black carbon) on the risk of CHD mortality.

## METHODS

We used linked administrative databases from the British Columbia (BC) health insurance system to assemble a population-based cohort. All Metro-Vancouver residents who met the following criteria were included in the cohort: (1) resided in the study region during the 5-year exposure period; (2) aged 45 to 85 years at baseline; and (3) without previous diagnosis of CHD.

This study included a 5-year exposure period (January 1994 to December 1998) and a 4-year follow-up period (January 1999 to December 2002). For the 5-year exposure period, individual exposures to community noise and traffic-related air pollutants were estimated at each person's residence using a noise prediction model and land use regression (LUR) models, respectively. For the 4-year follow-up period, CHD mortality information was retrieved from the provincial death registry. The associations of noise and black carbon with CHD mortality were examined using the Cox proportional hazards regression model.

We estimated annual average noise levels from road and light rail sources using CadnaA noise prediction model (Datakustik, Greifenberg, Germany). The main model inputs included: Traffic volumes, estimated using the 2003 transportation planning model EMME/2 (INRO Consultants, Montreal, Canada) used by Metro Vancouver transportation authority; fleet mix; road speed limits; traffic lights at intersections; road gradient (change in elevation along a given road); road surface (paved or loose surface); bridges (heights of the road segments above ground); buildings (height, footprint); and topography in the exposure assessment of road traffic noise. Railway noise exposure assessment was based on railway operation data including length of trains, velocity, percentage of disk brakes, and number of each type of train by day, evening, and night. For each municipality in Metro Vancouver, the data for each model input were available to a different degree and quality. Vancouver International Airport is Canada's second busiest airport and produces aircraft noise exposure forecast contours. We used their 2003 contours to estimate aircraft noise levels in the model area.

Annual average A-weighted equivalent continuous noise levels ($L_{DEN}$ dBA) were calculated for a 10 × 10 m grid. The $L_{DEN}$ metric integrates day noise levels (06:00 - 18:00 h), evening (18:00 - 22:00 h), and night (22:00 - 06:00 h), while reflecting increased sensitivity to noise in evening and night by adding a 5 dBA and 10 dBA weighting respectively. Based on the estimated noise levels, annual average total noise levels were calculated for each geographic area covered by a 6-digit postal code.

We used high-resolution land-use regression (LUR) models to estimate residential exposure to traffic-related air pollutants including black carbon, $PM_{2.5}$, $NO_2$, and NO in 2003 as described elsewhere. In brief, the concentrations of black carbon, $PM_{2.5}$, $NO_2$ and NO were measured in selected sampling sites (Henderson et al. 2007). Multiple linear regression techniques were used to estimate the quantitative relationships between measured air pollutant concentrations and the selected land use characteristics, and those most predictive variables were retained in the final models. Based on the LUR models, a smooth spatial surface of predicted annual average concentrations for each air pollutant was generated in a GIS with a resolution of 10 m. Annual average concentrations of these air pollutants were assigned to each postal code in the study region.

The noise data and air pollution data were linked to study subjects' residential history through their 6-digit residential postal codes. In urban areas, a 6-digit postal code typically represents one side of a city block a single high-rise building.

The study outcome was coronary heart disease (CHD) deaths (ICD9 codes 410-414, 429.2 or ICD-10 codes I20-I25). Preexisting disease was defined as hospitalization before 1998 for diabetes, COPD or hypertension. Individual socioeconomic status (SES) data were not available; we used neighborhood-income quintiles from the 2001 Statistics Canada Census to estimate SES. The method for neighborhood-income quintiles calculation has been described in detail elsewhere (Gan et al. 2011).

Baseline characteristics between study subjects across deciles of noise levels were compared using a chi-square test for categorical variables, one-way analysis of variance for continuous variables, and Tukey's post hoc analysis for pair-wise comparisons of continuous variables. Correlations between pollutants were examined using Spearman's rank correlation analysis.

The Cox proportional hazards regression model was used to determine the associations between noise or air pollution and CHD mortality; age, sex, preexisting comorbidity, neighborhood SES were included as covariates; air pollutants or noise were added in the final models. Person-years of observation were calculated from baseline to the date of death or end of follow-up (for those who moved out of the province, the last known date in the province).

We first treated noise levels as a continuous variable to calculate relative risks (RRs) for CHD mortality associated with a 10 dBA elevation in noise levels. We then treated noise levels as a categorical variable to examine exposure-response relationships by dividing study subjects into deciles based on the noise levels; RRs of coronary mortality were calculated for each decile by using decile 1 (lowest) as the reference category. Because there was no substantial difference in effect estimates across decile 2-9, only results for decile 1, decile 2-5, decile 6-9, and decile 10 are presented.

All statistical analyses were performed using SAS 9.2 (SAS Institute Inc., Cary, NC, USA). All statistical tests were 2-sided.

## RESULTS

For this cohort, the annual average noise level was 63.4 (interquartile range (IQR): 59.8 - 66.4) dBA (Table 1). Overall, noise levels were not strongly correlated with traffic-related air pollutant concentrations, the highest correlation was with black carbon (r = 0.44), the lowest correlation was with $PM_{2.5}$ (r = 0.14).

A total of 466,727 subjects met the inclusion criteria and were included at baseline. Among these, 13,992 (3.0 %) with missing air pollution data were excluded; 6,867 (1.5 %) with missing noise data were further excluded, which left 445,868 subjects for the analysis.

**Table 1:** Average noise levels and traffic-related air pollutant concentrations and correlation coefficients

| Pollutant | Mean (SD) | Median | IQR | Range | Correlation Coefficient[a] | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Noise | BC | $PM_{2.5}$ | $NO_2$ | NO |
| Noise, $L_{den}$ dBA | 63.4 (5.0) | 62.4 | 59.8-66.4 | 33.0-90.0 | 1.00 | -- | -- | -- | -- |
| BC, $10^{-5}$/m | 1.50 (1.10)[b] | 1.02 | 0.83-1.80 | 0.0-4.98 | 0.44 | 1.00 | -- | -- | -- |
| $PM_{2.5}$, μg/m$^3$ | 4.10 (1.64) | 4.04 | 3.22-4.81 | 0.0-10.24 | 0.14 | 0.13 | 1.00 | -- | -- |
| $NO_2$, μg/m$^3$ | 32.3 (8.1) | 30.8 | 26.7-35.2 | 15.3-57.5 | 0.33 | 0.39 | 0.47 | 1.00 | -- |
| NO, μg/m$^3$ | 32.2 (12.0) | 29.5 | 24.3-37.6 | 8.8-126.0 | 0.39 | 0.43 | 0.43 | 0.66 | 1.00 |

Abbreviations: BC, black carbon; IQR, interquartile range; SD, standard deviation.
[a] $P < 0.001$ for each correlation coefficient.

Table 2 shows the characteristics of study subjects at baseline by deciles of noise levels. Compared with those exposed to lower noise levels (decile 1), subjects exposed to higher noise levels were more likely to have preexisting comorbidities including diabetes, COPD, and hypertensive heart disease, and to have lower neighborhood SES.

**Table 2:** Baseline characterization of study subjects (N=445,868) by noise exposure decile

| Characteristic | Deciles of Noise Levels ($L_{den}$ dBA) | | | |
|---|---|---|---|---|
| | **Decile 1 (≤ 58)** | **Deciles 2-5 (59 - 62)** | **Deciles 6-9 (63 - 70)** | **Decile 10 (> 70)** |
| Men, % | 46.0 | 46.6 | 45.9 | 45.8 |
| Age, years | 59.3 (10.8) | 59.0 (10.6) | 59.4 (10.7) | 60.0 (10.9) |
| Comorbidity, % | | | | |
| Diabetes | 2.1 | 2.1 | 2.4 | 2.9 |
| COPD | 1.5 | 1.3 | 1.5 | 1.8 |
| Hypertensive heart disease | 4.3 | 4.0 | 4.3 | 4.8 |
| Any comorbidity | 6.6 | 6.3 | 6.8 | 7.9 |
| Income quintile, %[c] | | | | |
| 1 | 11.8 | 14.8 | 21.4 | 28.3 |
| 2 | 13.4 | 18.5 | 20.0 | 23.2 |
| 3 | 17.3 | 20.3 | 19.4 | 17.4 |
| 4 | 25.3 | 21.9 | 18.7 | 15.3 |
| 5 | 32.3 | 24.5 | 20.4 | 15.9 |

During the 4-year follow-up period 3,095 subjects died from CHD and the mortality rate was 1.83 per 1,000 person-years. Residential noise exposure was strongly associated with CHD mortality; a 10 dBA elevation in noise levels was associated with a 26 % (95% CI: 17-35 %) increase in the risk of CHD mortality. Adjusting for age, sex, preexisting comorbidity, and neighborhood SES halved the estimated relative risk, while adjustment for $PM_{2.5}$ and $NO_2$ had little influence on effect estimates. Adjusting for black carbon had a greater influence on the effect estimate, but a 10 dBA elevation in noise levels was still associated with a 9 % (95% CI: 1-18 %) increase in CHD mortality. For other cardiovascular diseases such as stroke, dysrhythmias, and congestive heart failure, there was no significant increase in mortality associated with a 10 dBA elevation in noise levels.

When study subjects were categorized into decile groups according to noise levels, compared with those in decile 1 with noise levels ≤58 dBA, subjects in decile 2-5 and decile 6-9 had little increase in coronary mortality, those in decile 10 exposed to noise levels >70 dBA had a 22 % (95% CI: 4-43 %) increase in coronary mortality after adjusting for all covariates and traffic-related air pollutants, suggesting that there was no linear exposure-response relationship between noise and coronary mortality (p=0.174 for test of linear trend across decile groups in the fully adjusted model) (Table 3).

Effects of noise and black carbon on coronary mortality were additive (Table 3). No multiplicative effect (p=0.980 for the interaction term in the fully adjusted model) was observed.

Stratified analysis shows that coronary mortality associated with a 10 dBA elevation in noise was greater for female, those aged ≥65 years, with preexisting comorbidity, and with higher neighborhood SES. However, there was considerable overlap in the 95% CIs between these subgroups.

**Table 3:** Relative risks and 95% Confidence Interval for coronary heart disease mortality by deciles of noise levels and quartiles of black carbon concentrations[a]

| Quartiles of Black Carbon ($10^{-5}$/m) | Deciles of Noise Levels ($L_{den}$ dBA) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Decile 1 (≤ 58) | | Decile 2-5 (59 – 62) | | Decile 6-9 (63 – 70) | | Decile 10 (> 70) | |
| | **RR** | **95% CI** | **RR** | **95% CI** | **RR** | **95% CI** | **RR** | **95% CI** |
| All* | 1.00 | Reference | 1.04 | 0.91-1.19 | 1.02 | 0.89-1.17 | 1.22 | 1.04-1.43 |
| Quartile 1 (0-0.83×) | 1.00 | Reference | 1.11 | 0.88-1.40 | 1.12 | 0.86-1.45 | 1.29 | 0.79-2.12 |
| Quartile 2 (0.84-1.02) | 1.05 | 0.78, 1.41 | 1.09 | 0.87-1.37 | 1.06 | 0.84-1.34 | 1.24 | 0.88-1.74 |
| Quartile 3 (1.03-1.80) | 1.09 | 0.79, 1.49 | 1.23 | 0.97-1.55 | 1.18 | 0.94-1.49 | 1.48 | 1.09-2.02 |
| Quartile 4 (1.81-4.98 | 1.50 | 1.04, 2.17 | 1.21 | 0.93-1.56 | 1.23 | 0.98-1.54 | 1.45 | 1.14-1.85 |

Abbreviation: $L_{den}$ dBA, annual day-evening-night A-weighted equivalent continuous noise level.
[a] Adjusted for age, sex, preexisting comorbidity, neighborhood income quintiles, and co-pollutants including $NO_2$ and $PM_{2.5}$.*
* same as (a) but also adjusted for BC

## DISCUSSION

This large population-based cohort study found that a 10 dBA elevation in residential noise levels ($L_{den}$) was associated with a 9 % increase in CHD mortality, after adjustment for the various covariates including traffic related air pollutants. There was no discernable linear exposure-response relationship, persons in the highest decile of noise levels (>70 dBA) had a 22 % increase in coronary mortality compared with those exposed ≤58 dBA.

A simple additive effect of the two exposures was noted (Selander et al. 2009). Also examined this but found while both exposure to noise and $NO_2$ showed independent elevation of risk, jointly no excess risk was observed (Selander et al. 2009).

These findings are largely consistent with prior studies of the combined effects of noise and traffic-related air pollution on CVD. All have supported a model in which both noise and air pollution are independent risk factors for CVD. Beleen et al. (2009) reported cardiovascular mortality increased 17 % (95 % CI: 0.94 to 1.45) for those exposed > 65 Vs. ≤ 50 dBA) after adjusting for black smoke; Risk of heart failure was 1.9. Risks associated with exposure to black smoke was similarly insenstive to adjustment for noise. Unlike our study, there was no discernible increase in CHD mortality. Selander et al. (2009) found that road traffic noise (≥50 vs. <50 dBA) was associated with a 12 % (95% CI: 0.95-1.33) increase in the risk of MI after adjusting for $NO_2$ and other cardiovascular risk factors; after excluding those with hearing loss or with other sources of noise exposure, the excess risk of MI increased to 38 % (95 CI: 1.11-1.71). And in a 5-year Swiss National Cohort Study with 4.6 million subjects, Huss et al. (2010) found that people exposed to aircraft noise ≥60 vs. <45 dBA had a 30 % (95% CI: 0.96-1.76) increase in MI mortality after adjusting for particulate air pollution, residential proximity to major roads, and other covariates; when the analysis was restricted to those who lived in their residences for at least 15 years, the MI mortality increased by 48 % (95% CI: 1.01-2.18).

The idea of independent effects has been described by Allen & Adar (2011) who They point out that it is consitent with other strands of evidence: both mechanism have plausible biological mechanisms, and animal and experimental evidence exists that should be less influenced by confounding as would occupational studies.

This study shows that the correlations between modeled noise and air pollution levels range from 0.14 ($PM_{2.5}$) to 0.44 (black carbon), which is within the range of correlations reported in previous studies. In practice, some road traffic factors such as speed, volume, and operating conditions may differentially affect the emission levels of noise and traffic-related air pollution, which may partly explain the low-to-moderate correlations between noise and traffic-related air pollution in the study region.

Previous findings on gender differences in the risk of coronary mortality associated with noise exposure are not consistent. Some studies found men are more susceptible to noise exposure than women (Babisch et al. 2005) whereas other studies found no differences between men and women (Beelen et al. 2009; Selander et al. 2009). Our study shows that men and women had similar risk of coronary mortality associated with noise exposure; however after adjusting for traffic-related air pollutants including $PM_{2.5}$, $NO_2$ and black carbon, women had a 7 % excess risk of coronary mortality compared with men, although the difference was not statistically significant.

This study had limitations that should be considered. The exposure assessment was based on the residential postal codes of study subjects to estimate the exposure at their residences. This method cannot precisely reflect actual individual exposure (Nethery et al. 2008). Nevertheless, these factors are likely to cause non-differential exposure misclassification, leading to underestimations of true risk of coronary mortality associated with exposure to noise and traffic-related air pollution (van Roosbroeck et al. 2008).

Second, because the cohort was constructed using linked administrative health databases from the provincial health insurance system, few individual-level cardiovascular risk factors were available. We adjusted for preexisting comorbidity including diabetes, COPD, or hypertensive heart disease. Because these comorbidities and CHD share common behavioral risk factors, adjusting for these comorbidities to some extent was able to reduce the influence of some uncontrolled risk factors and these comorbidities themselves on the effect estimates. In addition, it does not substantially confound the associations between fine particulate air pollution and CHD (Pope et al. 2004). Similarly, recent studies have also shown that cigarette smoking (either smoking status or daily smoking amount) did not substantially influence the associations between noise exposure and coronary events (Selander et al. 2009; Beelen et al. 2009).

Individual SES is a possible confounder for the observed association. As discussed before, individual SES was not available in this study, we used neighborhood income quintiles to approximately estimate individual SES. There is some evidence that this approach is valid for control of individual SES (Dominguez-Berjon et al. 2006; Krieger 1992). In addition, in a subgroup analysis of the study subjects (n=1,194) who participated in the Canadian Community Health Survey (2000-2001), neighborhood income quintiles were strongly associated with individual annual household income, education level, marital status, and daily fruit and vegetable intake (all $p<0.001$). Based on these results, we believe that including neighborhood income quintiles in the Cox model could effectively minimize the confounding effects of individual SES.

Finally, A-weighted equivalent sound pressure level based on the equal energy principle over some time period has been widely used in community noise measurement. This method may be appropriate for continuous noise such as road traffic noise, but it cannot reflect actual disturbance caused by a small number of high-level discrete noise events.

In conclusion, in this large population-based cohort study, we found that a 10 dBA elevation in residential noise levels ($L_{den}$) was associated with a 9 % increase in CHD mortality. There was no discernable linear exposure-response relationship, subjects in the highest noise decile (>70 dBA) had a 22 % increase in CHD mortality compared with those in the lowest decile (≤58 dBA). An IQR ($0.97\times10^{-5}$/m) elevation in black carbon concentrations was associated with a 4 % increase in CHD mortality. We found a simple additive effect between noise and black carbon on coronary mortality. These findings suggest that both noise and traffic-related fine particulate air pollution indicated by black carbon may be partly responsible for the observed associations between exposure to road traffic and adverse cardiovascular outcomes.

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# The effects of recorded traffic noise on hemodynamic parameters in healthy women – a pilot study

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## INTRODUCTION

Road traffic noise is known to increase blood pressure or cause arterial hypertension in adults (Babisch 2006). However, the effects of noise on hemodynamic parameters have rarely been studied. During an experimental noise exposure in young adults, Belojevic et al. (2003) showed strong vasoconstrictive and hypodynamic cardiovascular effect of noise, but no statistically significant effects on blood pressure and heart rate. At the time, the effects of noise exposure on the autonomic nervous system (sympathetic and parasympathetic activity or sympathovagal balance) were not investigated. In another experimental study in an occupational setting, Kristiansen et al. (2009) showed changes in systolic blood pressure and an increase in sympathetic activity among noise-exposed individuals, who were engaged in cognitively demanding work tasks. Finally, Graham et al. (2009) reported a significant effect of the indoor traffic noise exposure on cardiac parasympathetic withdrawal during sleep, but no effect of traffic noise on cardiac sympathetic tone.

Thoracic electrical bioimpedance (TEB) is a comprehensive method of non-invasive follow-up of major cardiovascular hemodynamic parameters, such as blood pressure, heart rate, cardiac index (a minute volume of heart per square meter of body area), systolic index (the amount of pumped blood during each systole normalized for body surface area), enddiastolic index (the volume of blood in a ventricle at the end of diastole normalized for body surface area), contractility (rate of shortening of myocardial muscle fibers), vascular resistance index (the resistance to the flow of blood in the vasculature normalized for body surface area), ejection fraction (the percentage of blood pushed in each heart beat, equal to systolic index divided by enddiastolic index), left cardiac work index (an indicator of the amount of work; the left ventricle must perform to pump blood each minute, normalized for body surface area), and thoracic fluid conductivity (Stojanov et al. 2005). Beside non-invasiveness, the advantages of TEB include continuous ('beat to beat') and simultaneous monitoring of all hemodynamic parameters, monitoring of heart rate variability and blood pressure, and the overview of sympathetic and parasympathetic activity (sympathovagal balance). Beside its use in the follow-up of patients with cardiovascular diseases in the clinical setting, thoracic electrical bioimpedance can be applied in many areas of research, including the assessment of physiological effects of noise.

The aim of this experimental study was to assess hemodynamic changes using thoracic electrical bioimpedance in healthy women during a 10-minute exposure to recorded traffic noise in comparison to quiet conditions before and after noise exposure.

## METHODS

This is a pilot phase of a large experimental study in the collaboration of the School of Medicine and the Multidisciplinary Center for Arterial Hypertension, Clinical Center of Serbia. Around 100 medical students were invited in 2009 to participate in the investigation. A total of 31 students (10 men and 21 women) agreed to take part in the study and signed an informed consent form. The study was approved by the Ethics Committee of the Clinical Center of Serbia.

All participants underwent a medical examination and blood pressure measurement by sphygmomanometer to exclude the presence of arterial hypertension. Participants with underlying diabetes (n=1), obesity (n=2), hypertension (n=1), arrhythmia (n=1), and participants with errors during the testing procedure (n=5) were excluded from the analysis. The final sample included 16 women and 5 men. We included only women in the study due to a small number of men for comparison. Mean age of the participants was 25.1±1.6 years.

All participants were asked to avoid smoking, drinking coffee or engaging in intensive physical activity for at least two hours before the testing procedure.

The testing procedure consisted of three phases: a 10-minute rest in quiet conditions ($L_{Aeq}$=40 dB) at start (before noise exposure), a 10-minute exposure to recorded traffic noise ($L_{Aeq}$=89 dB), and a 10-minute rest in quiet conditions ($L_{Aeq}$=40 dB) after noise exposure. Two loudspeakers were placed at both sides of a subject's head at the distance of 30 cm. Equivalent noise levels were measured with Hand Held Noise Level Analyzer Type 2250 'Brüel & Kjær' at the level of participants' ear. The participants were lying on their back during the experiment, connected to impedance cardiogram and electrocardiogram, with an oscillometric blood pressure device on left arm, and a two-finger cuff for plethysmography or 'beat to beat' blood pressure monitoring. The following hemodynamic parameters were monitored with thoracic electrical bioimpedance device (Task Force® Monitor, CNS System Medizintechnik AG, Graz, Austria): blood pressure, heart rate, cardiac index, systolic index, total vascular resistance index, and sympathovagal balance (a ratio between a low frequency power – sympathetic influences on heart rate, and a high frequency power – vagal or parasympathetic modulation of heart rate).

The differences between noisy and quiet conditions were tested with Friedman's test for several related samples and with Wilcoxon signed ranks tests for two related samples.

## RESULTS

Significant differences between the three experimental conditions were found for cardiac index (Friedman's test chi-square=14.926; p=0.001), systolic index (chi-square=8.222; p=0.016), and total peripheral resistance index (chi-square=8.375; p=0.015), but not for systolic pressure (chi-square=3.375; p=0.185), diastolic pressure (chi-square=2.317; p=0.314), heart rate (chi-square=5.375; p=0.068) and sympathovagal balance (chi-square=2.462; p=0.292).

Post hoc testing showed that cardiac index and systolic index were significantly decreased during noise exposure in comparison to quiet conditions before noise exposure, indicating a hypodynamic effect. On the other hand, peripheral vascular resistance was significantly increased during noise exposure, indicating vasoconstriction (Table 1).

Both systolic and diastolic blood pressures were significantly higher during noise exposure in comparison to quiet condition before noise exposure. Heart rate was similar during noise exposure compared to quiet condition before noise exposure, but was significantly higher during noise exposure in comparison to the quiet condition after noise exposure. The effect of noise exposure on sympathovagal balance was not statistically significant (Table 1).

**Table 1:** Hemodynamic parameters of the investigated women before, during and after noise exposure

| Hemodynamic parameters | Quiet condition at start | Noise exposure | Quiet condition after noise | Between group comparison* (p value) | |
|---|---|---|---|---|---|
| | | | | Quiet at start vs. noise exposure | Noise exposure vs. quiet after noise |
| Cardiac index ($l/(min*m^2)$) | 3.99±1.07 | 3.85±1.02 | 3.71±0.93 | 0.013 | 0.394 |
| Systolic index ($ml/m^2$) | 53.35±15.90 | 52.02±14.47 | 52.38±13.69 | 0.027 | 0.049 |
| Total peripheral resistance index ($dyne*s*m^2/cm^5$) | 1698.19±781.33 | 1823.88±836.07 | 1863.44±770.68 | 0.012 | 0.326 |
| Systolic pressure (mmHg) | 105.52±12.78 | 109.03±11.84 | 108.76±9.04 | 0.008 | 0.469 |
| Diastolic pressure (mmHg) | 67.05±11.09 | 69.92±12.27 | 70.92±9.47 | 0.023 | 0.733 |
| Heart rate (beat/min) | 76.62±15.64 | 75.32±12.77 | 71.63±11.16 | 0.339 | 0.026 |
| Sympathovagal balance | 1.02±0.88 | 1.00±0.58 | 0.88±0.49 | 0.998 | 0.102 |

Table legend: * Wilcoxon Signed Ranks Test

## CONCLUSIONS

Exposure to recorded noise level of 89 dBA for 10 minutes had strong vasoconstrictive and hypodynamic effects in healthy women, with a significant increase of blood pressure. Further studies with thoracic electrical bioimpedance on a larger sample including both sexes will be valuable in explaining the effects of acoustic stress on cardiovascular regulatory mechanisms of blood pressure.

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# The effect of aircraft noise exposure on quality of life and psychiatric problem: a report of the Bangkok Airport Study

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## INTRODUCTION

Opening in 1914, Don Muang (DM) Airport or Bangkok international airport was the first International Airport in Thailand. It was located in the northern suburbs of Bangkok in the area of 6.21 square kilometers. It was estimated that 80 airlines and more than 250 million passengers with 160,000 flights and 700,000 tons of cargo are used at the airport every year. Don Muang Airport was closed on September 28, 2006 and began to service again on March 25, 2007 for only domestic and charter flights, approximately 90,000, in 2007.

In order to become an aviation hub of Southeast Asia, the Royal Thai Government constructed a new international airport named Suvarnabhumi (SVB) airport. The new airport was located 25-kilometer away and in the eastern suburbs of Bangkok adjacent to Samutprakarn province. This inland airport was approximately 32.38 square kilometers, the new modern biggest international airport. It started full operation on 29 September 2007. This airport consists of 2 runways which could service 76 flights per hour, 45 million passengers per annum and 3 million tons of cargo per annum. The number of flights passing by Suvarnabhumi International Airport was recorded as 270,283 flights in 2007 (AOT 2007).

After opening the SVB airport, there is an ongoing social and political debate regarding the aircraft noise exposure which caused the change the quality of life (QOL) and increased psychiatric problem. WHO reported the health effect due to noise pollution. Aircraft noise could also be interference with speech communication, disturbance of rest and sleep, psychophysiological, mental and performance effects, effects on residential behavior and annoyance, and interference with intended activities (Berglund et al. 2000). All of these effects could have tremendous impacts on quality of life and develop psychiatric problem among residents living around the airport. However, the study about non-auditory effects is still limited.

The lack of knowledge about causal and temporal relationship between aircraft noise exposure and various health effects have prevented control measures for several airports. The opening of an inland airport like this was, therefore, an opportunity to demonstrate that quality of life and psychiatric problem could be affected by aircraft noise exposure.

METHODS

## Study area

The study areas in this study were communities around two international airports, SVB airport and DM airport. At the beginning of the study, before the opening of the new international SVB airport, we include the study communities of two areas by using the secondary data of noise contour map (MNRE 2001; Boeing 2005). Communities having NEF > 35 were selected as the study communities. The research team walked around in the areas to select the communities which had no confounding noise and same social structure. Finally, we selected 7 communities in this study; all of them were located within the range of 5 kilometers from either of each airport. One year after the open of the SVB, we followed up the same communities which was selected in the first survey.

## Tool

The questionnaire comprised of questions on potential determinants of variables such as personal characteristics, living condition, routine behavior and World Health Organization's quality of life (WHOQOL). The Thai WHOQOL –BREF version consists of 26 items which can be grouped into 4 dimensions namely, physical, psychological, social and environmental domains. Each item has 5 rating scores, from 1-5 score. Thus, the total scores ranges from 26-130. The reliability of this questionnaire was indicated by Cronbach's alpha coefficient, 0.9 (Mahatnirunkul et al. 1998).

For psychiatric effect, Thai version of self-administered General Health Questionnaires (Thai-GHQ 28) was used as a tool to detect having psychiatric problems in the communities. It is composed of 28-items. It can detect four domains of psychiatric problems namely somatic symptoms, anxiety and insomnia, social dysfunction and depression. Each item has four choices of answers; 1-not at all, 2-no more than usual, 3-rather more than usual and 4-much more than usual. For Thai GHQ, the scoring system for GHQ by Goldberg score (0-0-1-1) and the subject showing the score less than3/4 were categorized as "exceptional case" (Nilchaikovit et al. 1996).

## Data collection

Community response change in quality of life associated with the operation of the new International Airport was documented in two rounds of community survey. One round was conducted from August to September 2006 prior to the starting of the new airport operation while a second round was undertaken one year later. Self-administered questionnaires were distributed among adults older than 18 years of age by non-probability sampling i.e. to all households on the survey day. One person from each household, who filled in the questionnaire, became subject in this study. Data validity was checked when the questionnaires were collected.

## Statistical analysis

Statistical analysis were performed using SPSS for windows (version 11.5, SPSS Incorporated). For quality of life, comparison of baseline quality of life score between the groups was tested by t-test. The difference QOL scores between before and after opening SVB airport in each area was tested by pair t-test. The difference quality of life scores were calculated by subtracting the "before" score from the "after" score. These scores between two areas were tested by t-test. For psychiatric problem, the prevalence or incidence rate of exceptional GHQ was presented by percentage and 95% confidence interval. The difference rate between two areas was tested by Chi-square test. A p-value of less than 0.05 was considered significant.

## RESULTS

The total number of cohort in this project was 972 subjects at the beginning. After one-year follow up, some subjects are not reachable or not capable of responding or refused to participate again or move to other area. Finally, 417 subjects participated in the second-time survey, thus, yielding 42.9 percent of response rate. However, there was no difference in quality of life score among the respondents and non-respondents comparing between DM and SVB areas.

Most of subjects were female, middle aged, with low to medium education and medium socio-economic status. Residents living around SVB Airport had older age, lower level of education, more positive money status, but had longer duration of living in the area, higher proportion of underlying diseases than those living around DM Airport.

### Quality of life

The descriptive QOL score, before and after opening of new international airport of each community, were shown in Table 1. Before the opening of the new airport, the mean QOL scores of both areas were not statistically different (p=0.52). However, at one-year follow up, the mean QOL scores of residents living around the new airport were decreased. The different scores between before and after the opening of residents around SVB Airport decreased significantly (p<0.001) while the difference scores of residents around DM Airport were not significant. However, the magnitude of difference and dispersion of variance was larger among SVB residents than DM residents.

**Table 1:** Descriptive QOL score classified by area and time period

| Study sites | n | Mean ± Standard deviation (S.D.) of score | | |
|---|---|---|---|---|
| | | **Before** | **After** | **Difference** |
| **SVB** | | | | |
| - SVB 1 | 36 | 92.6±12.8 | 82.9±16.2 | -9.1±14.3 |
| - SVB 2 | 25 | 93.3±10.2 | 92.0±15.3 | -1.3±15.2 |
| - SVB 3 | 96 | 88.1±13.9 | 87.0±13.5 | -1.1±12.3 |
| - SVB 4 | 84 | 91.8±13.9 | 83.3±11.5 | -8.5±15.2 |
| **Total** | **241** | **90.6±13.5** | **85.7±13.6** | **-4.9±14.4** |
| **DM** | | | | |
| - DM 1 | 103 | 90.5±12.1 | 90.8±10.9 | 0.3±9.7 |
| - DM 2 | 44 | 94.1±11.8 | 94.2±11.0 | 0.1±10.1 |
| - DM 3 | 29 | 90.6±10.4 | 94.8±10.9 | 4.2±9.0 |
| **Total** | **176** | **91.4±11.8** | **92.3±11.0** | **0.9±9.7** |

### Psychiatric problem

Prior to the opening of SVB airport, the prevalence of exceptional GHQ was 21.99 % (95% CI = 16.73-27.26) in SVB-group and 18.18 %( 95%CI = 12.43-23.94 %) in DM-group. No significant statistical difference was found in prevalence rate of abnormal GHQ in the two groups (p=0.34). In the one-year follow up study significant statistical difference is found in prevalence rate and incidence rate between the two groups with p-value<0.001. The prevalence of abnormal GHQ are 39.42 % (95% CI=33.21-

45.63 %) in the SVB-group and 17.61 % (95% CI=11.93-23.30 %) in the DM-group (Figure 1).

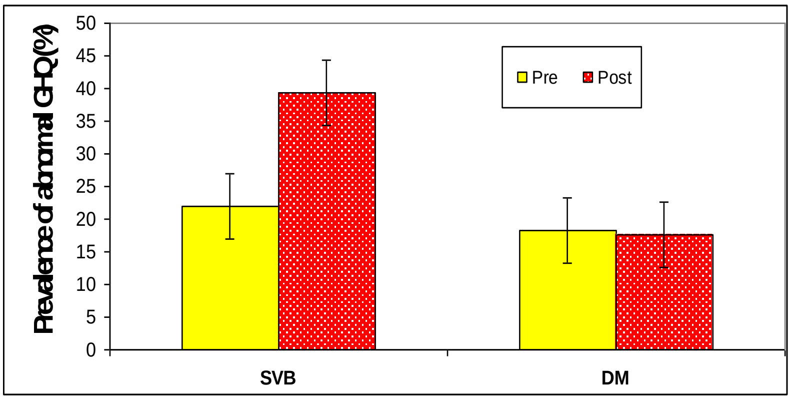


**Figure 1:** The prevalence rate of exeptional GHQ before and after the opening of the new international airport

## CONCLUSIONS

This study supports the temporal relationship between aircraft noise exposure and non auditory effect in risk of decreasing quality of life and having psychiatric problems among residents living around airport. Risk should be communicated for people living in prospective airport areas prior to the planning and implement of the airport expansion and construction.

## ACKNOWLEDGEMENT

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# Disruptive effect of urban environmental noise on the physiological recovery response after stress testing

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## ABSTRACT

The relationship between stress, physiological response and health has been extensively analyzed (Berglund et al. 1999; Ising et al. 1999; Maschke 2003; Muzet 2007; Stanfeld & Matheson 2003). There is also evidence of how continued exposure to noise is associated with certain diseases (hypertension, ischemic heart disease, sleep disturbances...). The main objective of this paper is to analyze the short-term effect of a disturbing noise source on the heart rate recovery after cognitive stress induced by a test. The method used was a crossed factorial design on two groups of 5 subjects/people randomized in which the sequence of exposure is inverted. (AB / BA; A: test with urban environmental noise, B: test with urban environmental noise + disturbing induced noise). Participants (n = 10) are monitored with a computer to record the heart rate at rest (baseline) and at the experimental stress situation (cognitive test). The results show that all participants, despite their order of exposure, present a higher rate of cardiac frequency in the stress testing compared to the baseline one. However, they recover more slowly to baseline rates when they are exposed to the disturbing noise situation, than when they are in a condition of environmental noise. As conclusions, we would like to highlight that urban environmental noise is a stressor which, in addition to other stress conditions, hampers the physiological recovery response. That is, disturbing noise could affect the standard physiological response of people to stress, obstructing the restorative function of urban spaces designed to be use in leisure and relaxation times.

Key Words: Urban noise, Health effect, Stress, Physiological response. Restorative function.

## INTRODUCTION

The results set out in this paper are part of a more general analysis that includes two further conditions to the one included here:

1. Identification of acoustic indicators which are valid to identify urban quiet areas where the urban environmental noise is pleasant (Memoli et al. 2009: García et al. 2010).
2. Assessment of the urban environmental noise from the point of view of its perception (psychosocial). A battery of specific tests (perceived stress, negative and positive emotions, soundscape perception....) were therefore designed (Herranz-Pascual et al. 2010; Botteldooren et al. 2011).

The general analysis seeks to analyze the relationship between these three types of measurements (physiological, acoustic and psychosocial) in order to discover the relationship between the three types of parameters and perform a crossed validation of the selected indicators. This analysis is not covered by this paper.

## Objective

The objective is to analyze experimentally the influence of noise levels generated by a noise pollution source in the physiological response of people under rest conditions and when performing cognitive tasks.

## Hypothesis

1. Persons exposed to acoustic environments with prevailing acoustic sources that generate noise pollution will present a greater cardiac frequency response in situations of non-activity (recovery and rest phases) and activity (answering questionnaires and stress tests).

2. Persons exposed to an acoustic environment with higher presence of noise source generating noise pollution, will present a longer delay in recovering the cardiac response after an induced stress test.

METHODS

## Design

The method used was a crossed factorial design on two groups of 5 subjects/people randomized in which the sequence of exposure is inverted (AB / BA; A: test with urban environmental noise, B: test with urban environmental noise + disturbing induced noise). The analysis is based on a 2x2x4 with three handling conditions:

1. The exposure or non-exposure of the persons to an acoustic environment with an acoustic source generating noise pollution.
2. Sequence of exposure to the extra disturbing noise source (group 1 sequence: Without extra noise source + With extra noise source; group 2 sequence: With extra noise source + Without extra noise source); and
3. Logging phases of the physiological response that consists of a succession of four phases: 3a – rest phase, 3b – questionnaire phase, 3c – induced stress phase, and 3d – recovery phase.

## Sample

The study consisted of ten people of both sexes (6 women and 4 men) which are distributed at random in two groups subjected to the same experimental conditions, but with exchange of exposure sequence to the extra disturbing noise source; the groups are designated as "1" or "2" depending on this condition, making up a crossed design (both groups receive the same experimental conditions but in reverse order). All the participants were informed and gave their consent to take part in the study.

## Procedure

One week prior to the experiment described in this paper being conducted, the ten participants underwent a series of tests that had a triple objective:

- Gradual adaptation of the participants to certain questionnaires and analysis that were going to be conducted as part of the project.
- Obtaining a physiological response base line of each individual that will enable an adequate analysis of the data during the experience.

- Gradual adaptation of the participants to the portable equipment to analyze the cardiac frequency: POLAR RS 400.

The participants were told to be at Tecnalia premises in the morning, where they were given instructions on the tasks to be performed that day. They were only told that they were going to be taken by car to another place. They were taken to a public square in the city of Bilbao which has been recently refurbished and is attractive and architecturally comfortable. The acoustic environment was dominated by urban environmental noise sources present in city centers: noise of traffic and pedestrians, along with sources characteristics of the place (water fountain and birds).

A series of tests (answering questionnaires and conducting a cognitive stress test) were conducted in this square, while they were monitored individually with the same pulsometer that had been previously programmed to store cardiac frequency records every 5 seconds.

**Table 1:** Sequential development phases of the experiment for each of the two groups

| | Experimental Condition: Noiseless | | | | Experimental Condition: Noisy | | | |
|---|---|---|---|---|---|---|---|---|
| | Phase | | | | Phase | | | |
| Group 1 (24/11/10) | Resting | Questionnaire | Stress test | Recovery | Resting | Questionnaire | Stress test | Recovery |
| | Experimental Condition: Noisy | | | | Experimental Condition: Noiseless | | | |
| | Phase | | | | Phase | | | |
| Group 2 (29/11/10) | Resting | Questionnaire | Stress test | Recovery | Resting | Questionnaire | Stress test | Recovery |

The experiment was run on two different days. The first group of five people were taken there on 24 November and the second on the 29th. The first received the "noiseless - noisy" sequence and the second "noisy-noiseless". The environmental and climate conditions were similar on both days and no event was detected that could significantly influence the expected results.

A brief description is set out below of the phases that are identical in both groups irrespective of the experimental condition:

- **Resting**: time spent relaxing when the participants had to minimize movements and which is the base line of the physiological state of the participants.
- **Questionnaire**: answering questions to collect information relating to emotions and perceived stress. The analysis of this information is not presented in this paper.
- **Stress test**: cognitive stress test which the participants undergo in order to increase their stress levels.
- **Recovery**: phase aimed at recovering the physiological conditions to the base line where the participants were encouraged to meet the same conditions as in the resting phase.

The cardiac frequency of the participants was monitored throughout the phases.

As can be seen in Table 1, the only difference between the two sequences is the experimental condition that refers to the acoustic environment in the zone:

- NOISELESS condition: acoustic environment with the typical noise sources of the urban setting where the experiment was conducted, that mainly included urban traffic (controlled by a traffic light), a water fountain, and pedestrians.
- NOISY condition: acoustic environment where an additional noise source was added to the NOISELESS condition which was a recording of the sound in one of the adjoining streets in the study zone. This second situation increased the background noise by 2 dBA and added more non-natural noise events (mainly horns and lorries going by). Adding this new noise source was aimed at making the acoustic environment noisier and a more disturbed space with respect to the NOISELESS situation, but keeping as similar as possible the previous conditions (van den Berg 2010).

To conduct the experience, the relevant permits were requested from the authorities to carry out the study and the times were provided to avoid interference from law enforcement agents. A specific urban area was prepared and isolated where five chairs were arranged where the participants were going to perform the tasks (see Figures 1 and 2).

**Figure 1:** Location of the hidden noise source for the participants

**Figure 2:** Location of the participants in the study area

For each of the groups, once the different phases in one of the experimental conditions had been completed, there was a break and the participants were taken to another location to have breakfast. While they were absent, the noise source was activated (or deactivated) so that they would not perceive a sharp change in intensity where they returned. Following the break, the participants returned to the experimental set and proceeded to repeat the aforementioned sequence of phases.

**Data analysis**

The data series of the cardiac frequency performed during the different phases and sessions of the experiment were exported to an Excel database. Four sheets (2x2) were created according to the group-sequence (day 24 vs. day 29) and the noise source condition (noisy-noiseless) with the recording series for each participant depicted graphically.

The average values per person and exposure phase were calculated in order to find a representative value of the effect on the heart rate in each of these phases. In order to analyze the results, the variance decomposition techniques of the general linear model implemented in the SPSS (Statistical Package for the Social Science, v18) program were used. The Brown-Forsythe robust test to contrast between-group means and the size of the Between-Subjects effects and within-subjects effects based on the Eta-squared ($\eta^2$) were included.

The regression slope of the recovery latency after the stress test is calculated to consider the second hypothesis. A gentler slope compared to a steeper one would mean a later recovery.

## RESULTS

Analysis of the data shows that each subject has an identifiable characteristic profile in the two sequences considered (noisy and noiseless), but there is also a great diversity in the profiles between subjects. Once all the cases were considered, it was difficult to observe a clear response pattern, due to the important uniformity of the heart rate response patterns by each participant.

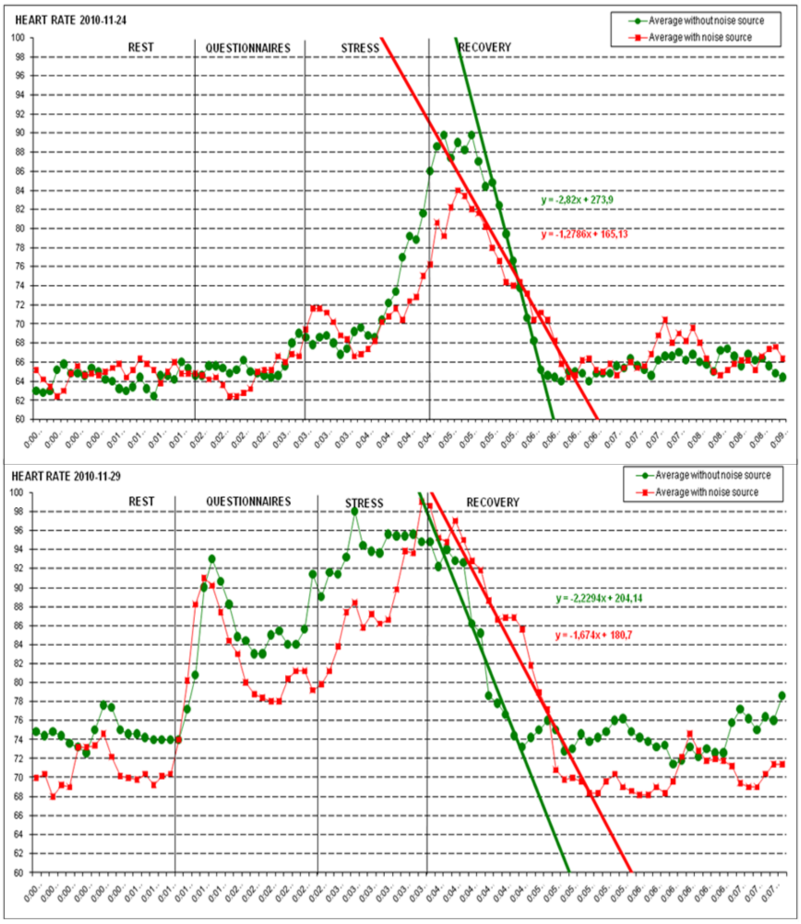


**Figure 3:** Average heart rate throughout the experiment. Calculation of the recovery latency slope

Taken overall, and after estimating the average heart rate for each moment of the test, the response parameters were obtained for each experimental condition (Figure 3). The upper part of the figure shows the average response of Group 1 (on 24/11/2010 with the "Noiseless - Noisy" sequence) and the lower part Group 2 (on

29/11/2011 with the "Noisy-Noiseless" sequence). In both cases, the heart rate in absence of disturbing noise appears in green and the noisy condition in red. The visual analysis enables identifying a low cardiac rate pattern in the first rest phase, in both groups and experimental conditions. In phase 2 (questionnaires), a higher response rate can be seen in group 2 compared to group 1, even though the between-group robust tests of means contrast (*Table 2*) did not reach statistical significance. The maximum heart rate readings are reached, as was to be expected, in the cognitive stress phase and there are no differences between groups or between conditions. In the last phase, there was a drop in the heart rate after the stress rate to values near to those at rest. In both groups, the drop in the heart rate slope was greater in the noiseless sequences (y=–2.82x+273.9, for group 1; y= –2.23x+204.1, for group 2) than the noisy ones (y=–1.27x+165.1; y= –1.67x+180.7, respectively).

**Table 2:** Average values (M) of hearth rate from experimental design and hypothesis testing

| | Group 1 | | Group 2 | | Comparisons * | |
|---|---|---|---|---|---|---|
| Experimental Condition → | Noiseless | | Noisy | | Between groups | |
| Phases | M | (95% CI | M | (95% CI | Mean Diff. | p |
| Resting | 65,1 | (54.2-75.9) | 70.3 | (59.5-81.2) | 5.2 | .453 |
| Questionnaire | 71.7 | (60.9-82.4) | 81.4 | (71.1-92.5) | 9.7 | .166 |
| Stress test | 79.3 | (66.9-91.7) | 93.4 | (80.9-105.8) | 14.1 | .102 |
| Recovery | 66.3 | (55.8-76.7) | 72.6 | 62.1-83.1) | 6.3 | .359 |
| Experimental Condition → | Noisy | | Noiseless | | | |
| Phases | M | (95% CI | M | (95% CI | Mean Diff. | p |
| Resting | 64.6 | (51.9-77.4) | 74.5 | (61.8-87.3) | 9.9 | .252 |
| Questionnaire | 69.1 | (59.4-78.8) | 85.0 | (75.3-94.6) | 15.9 | .129 |
| Stress test | 77.4 | (61.5-93.3) | 94.0 | (78.1-109.8) | 16.6 | .036 |
| Recovery | 67.2 | (54.9-79.4) | 76.6 | (64.4-88-8) | 9.4 | .248 |

| | | | |
|---|---|---|---|
| Multivariate contrast (Lambda Wilks): | $F_{(2,7)}$= 118.45 | p= .008 | |
| Within-group effect: Factor | $F_{(7,56)}$= 24.13 | p< .001 | $\eta^2$= .751 |
| Factor * Group | $F_{(7,56)}$= 1.99 | p= .112 | $\eta^2$= .199 |
| Between-group Effect | $F_{(1,8)}$= 2.58 | p= .148 | $\eta^2$= .243 |
| * Brown-Forsythe Test | | | |

Table 2 shows the average values of the heart rate for each phase of the experiment and according to the group and experimental condition. The multivariate hypothesis test shows a statistically significant effect on the within-subject comparisons [$F_{(7,56)}$= 24.12; p<0.001; $\eta^2$= .751], but not significant on the between-subject comparisons [$F_{(1,8)}$= 2.57; p= .148; $\eta^2$= .243] or in the interaction [$F_{(7,56)}$= 1.99; p= .112; $\eta^2$= .199].

## DISCUSSION

The aim of the study was to use an experimental study in a real urban environmental context to try to prove that an acoustic environment with greater noise pollution affects the physiological activity, estimated through the heart rate. The initial assumptions were that the heart rate would show a different pattern of greater intensity in the noisy condition and that the recovery rate after a cognitive stress rate would be quicker in noiseless conditions. The results obtained in our study do not allow the first of the hypothesis to be wholly accepted, while the second can be partially.

The study has significant limitations and therefore, the discussion and conclusions have to be taken with due care. A first and important limitation is in the characteristics of the sample. Apart from there being few cases (n=10), they have shown great heterogeneity in their heart rate response patterns, which made it more difficult to detect differences between the exposure conditions. In order to isolate the effect due to the exposure factor, the noise in our case, the effect of other variation sources needs to be controlled and the most important of these are those that are related to the response variable. Therefore, and in order for a more exhaustive control to be performed experimentally, the participants in the study should be selected using a uniform pattern of the physiological response chosen as a dependent variable. The heart rate was therefore chosen to be an easily accessible reading in experiment contexts in usual environments, but this reading is greatly affected by ordinary contingencies (small physical efforts, unexpected stimuli...). Wherever possible, and especially in experimentation contexts, at least two or three simultaneous readings of the physiological response effects (heart rate, conductance and/or reactance of the skin...) would need to be taken.

The inherent limitations of the study design used have to be added. We have tested the conducting of an experimental study in standard environmental conditions. Our aim was to attain greater external and ecological validity, but at the expense of sacrificing the internal validity. In other words, we have tried to establish what the physiological response is under normal conditions, but the possible interference of environmental factors other than noise may have distorted the response and, therefore, the certainty with which we can attribute the changes of the heart rate to the noise effect. In future approaches to the study of the effect of environmental noise on physiological response and health, it may be appropriate to use a combined design that implies an initial study phase in the laboratory (to increase the internal validity) and a second phase under natural conditions (attain the ecological and external validity).

Despite these limitations, and as the observed data have not met our initial hypotheses, we consider that the results do open up an interesting line of research. It was first noted that the recovery rate of the heart rate at stabilization or rest levels under the noisy condition was slower than under the noiseless condition. In other words, disturbing noise could be acting as another stressor that prevents the recovery of the physiological rate. Or, put another way, the absence of disturbing noise enables a greater recovery of the physiological rates. Given that this statement is only a hypothesis that will have to be strictly tested. There is evidence that has associated disturbing and intense noise to physiological and also emotional changes (Donnerstein & Wilson 1976; Miedema 2007; Ramirez et al. 2004). In this respect, urban noise, and more specifically traffic noise, is a stressor that influences our day-to-day performance and our health (Jonah et al. 1981).

On the other hand, no statistically significant differences were found in the heart rate patterns according to the exposure conditions and we could not therefore conclude that noise increases the heart rate. However, it should be noted that the size of the effect noted in the within-subjects comparison - associated to the noisy/noiseless condition - is .243, considered as a clear effect (Cohen 1988).

## CONCLUSIONS

An environmental experiment was conducted to try to provide the influence of disturbing noise on the physiological response, and indirectly on the health. It is one of the first studies of this type conducted so far. Our results are not conclusive, but open up an interesting and promising line of research as they show that there is evidence that associates intense and disturbing noise to not only physiological, but also emotional changes (Ouis 2001). In this respect, urban noise may be a stressor that influences our day-to-day performance and our health. Therefore, encouraging the reducing of acoustic environmental pollution would help to protect, and even improve, people's health. New evidence from other experiments and/or research groups would be welcomed and would enable a better design of the experimental studies for a more correct verification of the impact of noise on health.

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# Reviewing evidence on noise exposure and non-auditory health effects in the European Network for Noise and Health (ENNAH)

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ABSTRACT

The European Union Framework 7 (EU FP7) funded European Network for Noise and Health (ENNAH) project brings together 33 European research centers with the aim of establishing a network of experts and informing future research directions and policy needs in Europe. Part of the work activity has been to review evidence on noise and health; specifically to (i) provide a state of art summary of knowledge on noise exposure and non-auditory health effects, (ii) to identify gaps in the evidence and (iii) to make recommendations for further research.

Methods used to achieve this have been extensive database and on-line literature searches to identify published and grey literature studies, three ENNAH workshops (two specific to the literature review) and discussions with ENNAH partners.

It was decided early on not to attempt a large-scale general review of evidence as several very high quality reviews were in use or in preparation, so literature review work has centred around a review of reviews including a ranking of these using quality criteria adapted for this purpose, identification of gaps in the literature and systematic reviews in specific areas where synthesis of evidence was considered to be lacking such as noise sensitivity and health.

The dissemination plan for the literature review work has focused on making the key findings of the literature search easily accessible for the project partners. General information and the final report will be made accessible as a publicly available web document with 'click-through' facility on the ENNAH website.

## INTRODUCTION

Environmental noise, caused by traffic, industrial and recreational activities is considered to be a significant local environmental problem in Europe. Noise complaints have increased in Europe since 1992 and it is estimated that roughly 20 % of the Union's population or close to 80 million people suffer from noise levels which scientists and health experts consider being unacceptable (European Commission 1996).

There is increasing evidence that environmental noise exposure has a range of impacts on health and well-being. This evidence has recently been reviewed by the World Health Organization (WHO 2011) as part of the project to estimate the burden of disease from environmental noise and to develop night noise guidelines for Europe (WHO 2009), as well as by UK governmental bodies (Health Protection Agency 2009; Berry & Flindell 2009a, b). It is well recognized that environmental noise is related to annoyance and has impacts on sleep. More recent studies suggest effects on hypertension and cardiovascular disease and evidence for links with cognitive development in children (WHO 2009; Clark & Stansfeld 2007; Babisch 2006). One of the ways in which these effects may be mediated is via activation of the sympathetic nervous system as increases in levels of stress hormones in the blood have been measured in relation to environmental noise exposure. However, the effects on mental health are less clear – there is evidence for effects on psychological symptoms but not for clinically defined psychiatric disorders (Clark & Stansfeld 2007).

The European Network for Noise and Health (ENNAH), is a two year program funded under the EU seventh framework program environment theme that started in September 2009. It was set up to establish a research network of experts on noise and health to establish future research directions and policy needs in Europe with respect to the effects of environmental noise exposure on non-auditory health outcomes. ENNAH includes members from more than 35 institutions representing all parts of Europe including eastern member states. A key part of the ENNAH program has been a review of the existing literature on environmental noise exposure and health focusing on (i) the consolidation of existing state of the art knowledge and (ii) the identification of gaps in the evidence to identify future research needs and hypotheses to be tested.

## METHODS

### Scoping of the literature review

The scope and focus of the literature review was identified through a first workshop in September 2009 immediately following on from the launch meeting in September 2009 at which most of the ENNAH members were present. A combination of formal presentations from a range of experts, small group work and general discussions were used to define general principles with respect to the literature review. It was agreed that the task of identifying and reviewing all the literature again from scratch was unnecessary as there were several authoritative reviews already published or in preparation (for example: Berry & Flindell 2009a, b; Health Protection Agency 2009; WHO 2009, 2011).

The following objectives of the review were agreed:

- To summarize previous research by identifying previous reviews and authoritative studies
- To identify gaps in previous research
- To rank gaps in order of importance in terms of (a) scientific needs (b) policy-making needs
- To conduct limited literature searches in specific topics

It was decided that the review would concentrate on the above objectives and it was realized that it was unlikely that there would be scope for a quantitative meta-analysis, unless in a very specific topic area. It was considered important to consider literature not in English and this would be facilitated by the multi-national and multi-lingual membership of the network. It was agreed that the literature review would focus on health effects rather than cost-benefit analyses. Work on occupational effects of noise would need to be referred to as, although exposures are in general higher, there may be some analogy with effects expected in a population. It was noted that it might be necessary to consider literature from decades preceding the start of some of the readily available electronic databases of scientific literature e.g. some earlier studies in the 1970s did examine aggression and noise in laboratory studies.

Attempts were made to link with networks and large groups working in the area of noise and health e.g. the ENNAH literature review workshop included a talk from Prof Jian Kang from the Acoustics group, Sheffield University about soundscape research and the COST network (http://soundscape-cost.org/)

A second literature review workshop was held in June 2010 to identify and explore in depth literature relevant to the research gap areas recognized in the first literature review workshop and provide recommendations for future health studies. Talks and focused discussions were held on the following topic areas identified in the first workshop: sources of noise, occupational noise, noise and co-exposures, vulnerable groups, noise characteristics, acute vs. long term effects of noise, stress and social impacts, positive effects of noise and noise reduction interventions. Following this workshop, three topics (noise annoyance and sensitivity, noise co-exposures, reproductive health effects of noise) were identified for specific substantive reviews.

### Identification of existing reviews

Authoritative general reviews of the health effects of environmental noise were identified by the following means: electronic database searches, grey literature searches, emailing ENNAH WP2 workshop attendees, citation by other papers or reports for governmental bodies (e.g. Berry & Flindell 2009a, b). The reviews were grouped by topic area and ranked using a 10 point scoring system for quality.

### Ranking of evidence and of gaps in evidence

Ranking of scientific evidence for some outcomes has been attempted in some of the reviews identified in the literature review work package. An attempt to rank all of the evidence and the gaps in evidence using the combined expertise of ENNAH members is in progress. At the ENNAH ‘New Strategies for Noise and Health Research in Europe’ workshop in February 2011, attended by many of the ENNAH participants, a brief questionnaire was used to make an initial ranking of the nature of the evidence for associations between environmental noise from aircraft, rail and traffic sources and various outcomes e.g. annoyance, cardiovascular disease etc. as sufficient limited or inconclusive or lacking. Participants were also asked to identify the three most important topics in terms of scientific needs and policy needs in noise and health research. This exercise produced a lot of discussion and will feed into a more detailed ranking exercise using web-based survey tools. The results of this are expected to help to focus future research efforts and inform policy needs.

## RESULTS

### Identification of existing reviews

Existing authoritative reviews were identified and abstract and weblinks were made available to ENNAH members (where permitted given copyright issues – see below), through the ENNAH website. This was indicated in a database listing (Figure 1), currently made available for ENNAH members on the ENNAH website with the intention of making this publicly available by the end of the project. The quality of each review has been indicated by color from yellow to red (where red was highest quality). It was difficult to score some grey literature reviews so these were identified in grey.

Topic(s) covered by the review paper

| Paper | Grey literature | Annoyance | Blood pressure | Cardiovascular disease | Co-exposures | Noise sources(1) | | | | | Mood, performance (inc. cognitive development) | Sleep | Sensitivity | Stress+ hormone | Vulnerable groups |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Aircraft | Road traffic/ environmental | Rail | Occupational | Low freq. | | | | | |
| Babisch (1998) | | * | * | * | | | | | * | | | | | | |
| Babisch (2000) | | (*) | * | * | | * | * | | | | | | | | * |
| Babisch (2003) | | | | | | * | * | | * | | | | | * | |
| Babisch (2004) | | (*) | | * | | * | * | | | | | | | | |
| Babisch (2006a) | | * | * | * | | * | * | | | | | | | | * |
| Babisch (2006b) | * | | * | * | | | * | | | | | | | | * |
| Babisch (2008) | | | | * | | | * | | | | | | | | |

Colour coding: 1-4 points: yellow 5-7 points: orange 8-10: red

→ Better quality

**Figure 1:** Screen snapshot of first page of spreadsheet of general reviews ranked by quality (except grey literature indicated by grey color)

## Specific topic areas undergoing further literature review

The following areas were identified for further follow-up and are the subject of substantive reviews currently in progress:

(i) Noise co-exposures and health outcomes. This review into potential confounders and effect modifiers of noise effects is being led by Jurgita Lekaviciute and Stylianos Kephalopoulos from the European Commission Joint Research Centre, with input from ENNAH literature review work package members. Air pollution is a major co-exposure, but other exposures such as heavy metals, vibration and electromagnetic exposures may potentially confound or interact with noise effects.

(ii) Noise sensitivity and noise annoyance in relation to health outcomes. Some groups with high self-reported noise sensitivity or high levels of noise annoyance may be more vulnerable to the health effects of noise than the general population. However, very few studies have directly reported the associations between noise sensitivity or annoyance and health outcomes – studies tend to either examine noise levels in relation to noise annoyance or adjust for annoyance or sensitivity in analyses of associations between noise and health outcomes. A systematic review is in progress led by one of the authors (Helga Laszlo) with input from literature review work package members. A total of 9,160 records initially identified as possibly relevant, which has now been reduced to <100 using exclusion criteria, as most of the studies did not look at direct relationship with health outcomes.

(iii) Noise and reproductive outcomes. There is surprisingly little information about associations between environmental noise and reproductive outcomes. If the stress mechanism is important in mediating health effects of environmental noise such as hypertension and cardiovascular disease risk, then environmental noise might also have impacts on reproductive health including birth weight. A systematic review is underway, being led by Dr Gordana Ristovska of the Institute of public health of the Republic of Macedonia.

**Further issues identified as gaps in the literature**

It was noted that the main health outcomes studied to date have been cardiovascular health, mental health and psychological/psychiatric health. Health outcomes not or poorly studied to date e.g. respiratory health, developmental effects including birth outcomes (birth weight, miscarriages), stress mediators (cortisol, insulin resistance, abdominal obesity, blood lipids), sleep disturbance in infants, immune system dysfunction, and general health status. The following additional research gaps were identified:

- Cognitive effects of noise
- Recreational noise e.g. personal stereo devices
- Multiple sources of noise
- Acute vs. chronic effects of noise
- Effects of low frequency noise
- Noise effects on the metabolic system
- New sources of noise such as wind farms
- Observed health benefits (if any) of noise reduction schemes
- Interventional studies of noise reduction
- Positive effects of noise and positive soundscaping.

It was also recognized that there are many uncertainties related to exposure estimation, including choice and implementation of noise models, variability in noise measuring devices (if measurements are used), within-house variability in differences between outdoor and indoor sound levels, effects of opening windows, impact of sound insulation, lack of information on personal exposures (occupational exposures, personal stereo devices, community noise and protective factors e.g. deafness), impact of distance from source, average noise levels vs. noise events above a certain noise threshold, habituation effects etc.

**Copyright issues**

Copyright issues affect the dissemination of the results of the literature search. Because of copyright issues, many of the identified studies on noise and health could not be freely circulated in full among the partners nor published on the ENNAH website for the general public. Additionally, the 33 ENNAH partners were from different institutes with different licenses to download and print papers. According to copyright law, redistributing the articles on PubMed central needs the permission of the copyright holder, except for PMC articles in the open access subset. Even the circulation of journals with 'free access' documents depend on the open access agreement associated with the article (e.g. a creative commons license). Circulating a copy on behalf of the author is not allowed, unless circulating a copy to peers is included in the copyright transfer agreement. Web reports such as those from the WHO and (UK) Health Protection Agency are often subject to copyright where, although reports are free to download, permission must be sought for non-commercial redistribution so only links can be provided. As a result, the work packages were only able to provide a publications list, the citation and a link to the publication on the publisher's website but not the full article. Access to the full-text was available to those with permitted access via their institutions or personal journal subscriptions.

## CONCLUSION

The ENNAH project literature review work package has attempted to identify all major current general and cause-specific reviews on health effects of environmental noise and to rank these according to quality. This information is currently available on the ENNAH website to members and will be made publicly available by the end of the project in August 2011. While there have been a number of substantive reviews of the health effects of environmental noise, including most recently the WHO publication 'Burden of disease from environmental noise' (WHO 2011), most of the research in this field to date has focused on cardiovascular disease, cognitive impairment in children, noise annoyance and sleep disturbance. A number of important gaps in the literature have been identified, including questions about exposure assessment and co-exposures, lack of information on health effects of noise mitigation measures or potential benefits of soundscaping and poorly studied outcomes such as reproductive health outcomes and respiratory disease. Substantive reviews by ENNAH members are now underway with respect to co-exposures including air pollution, reproductive health and noise sensitivity. Finally, the literature review work package has been involved in attempting to rank the gaps in terms of evidence and policy needs, to help direct future research in this field.

## ACKNOWLEDGMENTS

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# The need for and access to quiet areas in relation to annoyance, health and noise-sensitivity

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## INTRODUCTION

This paper presents the findings of an explorative study into the association between annoyance, subjective health and medication use and access to, the need for and dissatisfaction with access to places usually referred to as "quiet areas". To this end, data from a neighborhood survey in 2006 among 3,607 persons of 18 years and older in The Netherlands (Kruize et al. 2011), were re-analyzed.

Due to the rapid urbanization in the Netherlands, the characteristics of (green) recreational areas within cities are changing and will increasingly become scarce. From a public health point of view this is an unwanted trend, since there is sufficient evidence that spending time in green places with relatively low levels of noise or preferably areas with high acoustic quality (Brown 2010) is beneficial for our health and well-being (Gezondheidsraad 2006). One of the mechanisms may be that spending time in areas with high acoustic quality can help restore or compensate for the adverse health effects of noise in the residential environment. The hypothesis is that health benefits can be obtained by spatial variation in noise levels (Gezondheidsraad 2006). But how large should this spatial variation in sound levels be in order to obtain health benefits and at what aggregation level (city-level, neighborhood level, and street level) does this spatial variation play a role? The very limited research into the health benefits of spending time in areas with high acoustic quality near their homes suggests that a quiet side of a home, but also access to quiet in the immediate home environment, reduces annoyance by noise (Gezondheidsraad 2006; Kleaboe 2001; Kleaboe et al. 2002; Gidlöf-Gunnarsson & Öhrström 2007).

One of the major obstacles for research and policy in this area is that it is hard to characterize and identify areas with high acoustic quality. The existing models describing the relation between noise exposure and health (Gezondheidsraad 1994) don't take restoration and compensation processes into account. Moreover, these models are focused on the effects of long-term exposure to noise. As has been demonstrated by a number of studies (Devilee et al. 2010), assessments based exclusively on noise levels provide only a limited information about what people experience as quiet and what can disturb such perceived quiet.

The importance of these findings is amplified by study results in which a high percentage of Dutch residents indicated the importance of quiet and the need for areas that are quiet and calm (Franssen et al. 2004). This does not necessarily mean that people actually visit these areas, since this actual behavior is determined by many factors. It has been shown that people's behavior affects their appreciation and perception: the more people make use of a recreational area, the more they find it attractive (Crommentuijn et al. 2007). Analogue to what is found in studies investigating the relation between green and health (Maas 2009) it is suggested that people's perception of the attractiveness of quiet, and the perception of the acoustical quality of an area is associated with health.

## METHODS

Participants were 3,607 persons of 18 years and older, who were recruited from more than 9,500 residents of 22 neighborhoods (including 947 postal code areas (6PPC)) across 14 municipalities in the Netherlands. The selection and recruitment of the participants has been described in detail elsewhere and contained several steps (Kruize et al. 2011). Neighborhoods were selected according to level of urbanization, and contrasting levels of accumulations of noise exposure, air pollution ($NO_2$), and availability of green and matched on socio-economic status. Within the selected neighborhoods, participants received an in-depth postal questionnaire that included questions on their living situation, health, wellbeing, perception and behavior, and potential confounding factors. The response rate was 40 %.

### Measurement of the need for and access to areas with high acoustic quality

The use of areas with high acoustic quality was measured by asking how often the respondent visited a quiet area for relaxation purposes. Answers were indicated on a 5-point category scale ('almost every day', 'at least once a week', 'at least once a month but not every week', 'at least three times during the past year', 'but not every month', and 'less than three times a year'). Satisfaction with access to quiet areas was measured by asking whether the respondent is satisfied with the number of quiet areas within walking or biking distance from his/her dwelling. Answers were indicated on a 5-point category scale ('very satisfied', 'satisfied', 'not satisfied but also not dissatisfied', 'dissatisfied', and 'very dissatisfied'). The need for quiet was measured by asking whether the respondent had the need to visit a quiet area. Answers were indicated on a 4-point category scale ('never', 'seldom', 'sometimes', and 'often').

### Measurement of annoyance and health

Annoyance due to road traffic noise at roads with a maximum speed of 50 km/h, > 50 km/h, and rail traffic noise, was measured by means of the standard ISO-question ISO 2001). Answers were indicated on an 11-point scale from 0 ('not at all annoyed') to 10 ('extremely annoyed').

Self-reported physical health was measured by a single general health question from the RAND-36 (van der Zee & Sanderman 1993) and by means of the 'Somatization'-scale of the Four-Dimensional Symptom Questionnaire (4DKL) (Terluijn & Duijsens 2006). Self-reported mental health was measured by means of the 'mental health scale' of the RAND-36 (van der Zee & Sanderman 1993). Self-reported high blood pressure, respondents was measured by means of a question about a (diagnosed) high blood pressure during the past 12 months and treatment by a specialist for high blood pressure. Medication use was inventoried for the past two weeks for (i) heart, blood vessels or blood pressure, (ii) sleep medicines or tranquilizers, and (iii) anti-depressives.

### Statistical analysis

To assess the association between annoyance, self-reported physical and mental health and medication use and need for, access to and dissatisfaction with access to quiet areas, multi-level logistic regression analyses by means of generalized linear mixed models were carried out using the GLIMMIX procedure in SAS version 9.2. Multilevel modeling takes into account the hierarchical structure of the data and enables effects at several levels to be included into the same model. For the analyses the following levels showed to be important: municipality, postal code area (6PPC), and respondent level.

As a result of the multi-level logistic regression, Odds Ratio's (OR) and their 95% confidence interval were analyzed. The models included age (yrs), gender, Body Mass Index (kg/$m^2$), ethnicity, level of urbanization, cumulative noise exposure level, self-reported noise sensitivity, and indicators of socio-economic status (the respondents' employment status and education level) as potential confounders. Statistical significance was tested using a Wald Chi-square test.

## RESULTS

Table 1 presents some general characteristics of the participants that were included in the analysis. Compared to Dutch national numbers where 32 % of the Dutch population of 16 years and older had sometimes or often the need to visit a quiet area (Franssen et al. 2004), the need to visit areas referred to as 'quiet' is high among the participants (more than 60 %).

**Table 1:** General characteristics of the participants included into the analysis (N = 3,607)

| **Characteristic** | |
|---|---|
| % women | 55.9 |
| Average age in yrs (SD) | 47.1 (16.1) |
| | |
| % employed[a)] | 69.5 |
| % high educated | 57.3 |
| % ethnic minority [b)] | 20.3 |
| % (very) strongly urban[c)] | 54.2 |
| | |
| Yearly averaged noise level ($L_{den}$) in dB(A)<br>Road traffic noise<br>Rail traffic noise | <br>55.9 (6.4)<br>48.2 (11.0) |
| | |
| % Visits often a quiet area | 53.9 |
| % Dissatisfied with access to quiet areas | 9.2 |
| % Need to visit a quiet area | 60.5 |

a) Person with a payed job;
b) person from who at least one of the parents has not been born in the Netherlands (CBS-definition);
c) defined as an area with 1,500 addresses per $km^2$;
Abbreviations: N = population size, SD = Standard Deviation, $L_{den}$ = Day-evening-night level

### Use of areas with high acoustic quality

Annoyance due to road traffic noise at roads with a maximum speed of 50 km/h was significantly related to the use of areas with high acoustic quality ($\chi^2$ = 6.9, df = 1, p = 0.009): in the severely annoyed group more persons reported that they often visited a quiet area than in the reference group. After adjustment for potential confounders, an OR of 1.43 (95%CI 1.07 – 1.92) was estimated. Persons who (moderately) agree with the statement 'I am sensitive to noise' more often reported that they visited a quiet area than the persons who did not agree at all with this statement ($\chi^2$ =

17.8, df = 4, p = 0.001). Other confounders, that had a significant effect on the use of quiet areas, were the level of urbanization, education level and body mass index.

Figure 1 shows the fully-adjusted associations between annoyance, self-reported health, medication use and the use of areas with high acoustic quality. After correction for potential confounders, annoyance due to noise from rail traffic (OR: 1.64 (95% CI: 1.10 – 2.46)), and low self-reported mental health (OR: 1.33 (95% CI: 1.05 – 1.68)) were statistically related to the use of quiet areas. No associations were found between annoyance due to noise from road traffic at roads with a maximum speed higher than 50 km/h, self-reported physical health, self-reported hypertension and medication use.

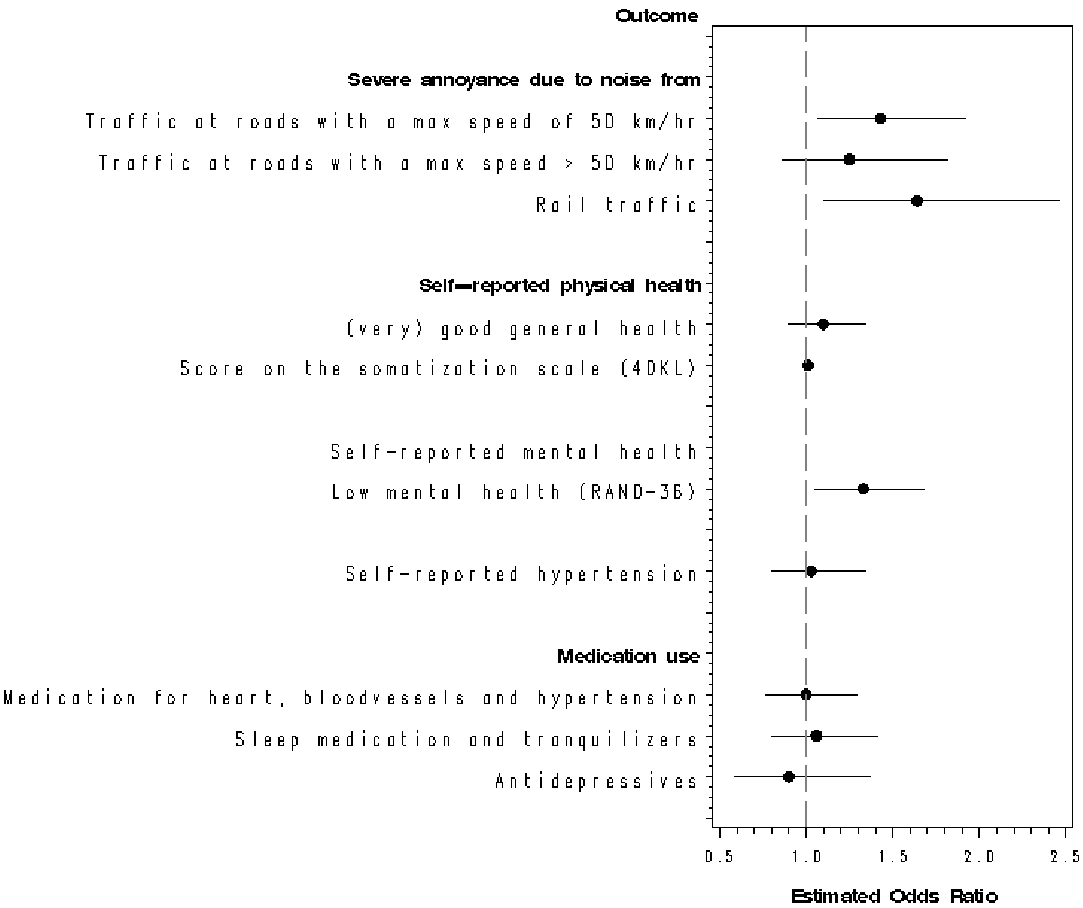


**Figure 1:** The association between annoyance, self-reported health, medication use and the use of areas with high acoustic quality, after adjustment for confounders. The circles correspond to the estimated difference between persons reporting that they often visited a quiet area and persons not reporting that they often visited a quiet area

## The need to visit areas of high acoustic quality

Annoyance due to noise from road traffic at roads with a maximum speed of 50 km/h was significantly related to the need to visit areas with high acoustic quality ($\chi^2$ = 52.3, df = 1, p<0.0001): in the group who were severely annoyed, more persons reported that they had a need to visit a quiet area than in the reference group. After adjustment for potential confounders, an OR of 3.46 (95% CI 2.38 – 5.01) was estimated. Persons who (moderately) agree with the statement ‘I am sensitive to noise’ more often reported that they had a need to visit a quiet area than the persons who did not agree at all with this statement ($\chi^2$ = 65.7, df = 4, p<0.001). Other confounders that had a significant effect on the need to visit quiet areas were the level of urbanization, ethnicity, education level, and body mass index.

Figure 2 shows the fully-adjusted associations between annoyance, self-reported health, medication use and the need to visit areas with high acoustic quality. After correction for potential confounders, annoyance due to noise from road traffic at roads with a maximum speed higher than 50 km/h (OR: 2.60 (95% CI: 1.67 – 4.05)), annoyance due to noise from rail traffic (OR: 2.16 (95% CI: 1.35 – 3.45)), the score on the somatization scale of the 4DKL (OR per increase of 1 unit on the somatization scale: 1.04 (95% CI: 1.02 – 1.06)), and a low self-reported mental health (OR: 1.59 (95% CI: 1.24 – 2.03)) were statistically related to the use of quiet areas. No associations were found between self-reported general health, self-reported hypertension and medication use.

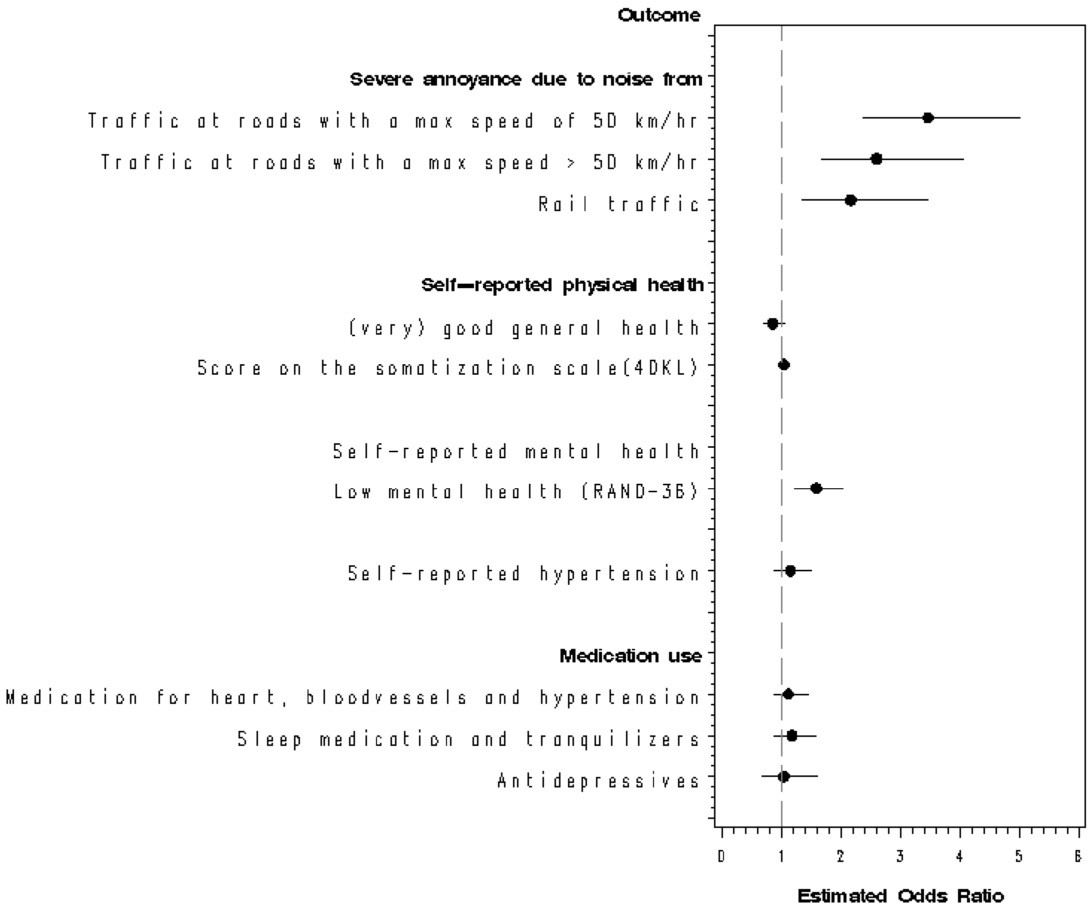


**Figure 2:** The association between annoyance, self-reported health, medication use and the need to visit areas with high acoustic quality, after adjustment for confounders. The circles correspond to the estimated difference between persons reporting that they often have the need to visit a quiet area and persons not reporting that they often have the need to visit a quiet area

## Dissatisfaction with access to areas of high acoustic quality

Self-reported general health was significantly related to dissatisfaction with access to areas of high acoustic quality ($\chi^2$ = 16.9, df = 1, p<0.0001): in the group who perceived their general health as (very) good, less persons reported that they were *dis-*

satisfied with the access to quiet areas than in the group who perceived their general health not as good or very good. After adjustment for potential confounders, an OR of 0.53 (95% CI: 0.38 – 0.74) was estimated. Confounders that were significantly associated with dissatisfaction with the access to quiet areas were noise exposure level and education level.

After correction for potential confounders, the score on the somatization-scale of the 4DKL (OR per increase of 1 unit on the somatization-scale 1.07 (95%CI: 1.04 – 1.09)) and a low self-reported mental health (OR: 1.61 (95%CI: 1.11 – 2.32)) were related to dissatisfaction with the access of areas with high acoustic quality. No associations were found between self-reported hypertension and medication use and dissatisfaction with the access to quiet areas.

## Discussion and conclusion

In this paper we explored the association between annoyance, subjective health and medication use and the need for and access to places usually referred to as “quiet areas”. After correction for possible confounding factors, we found statistically significant associations between annoyance due to noise from road- and rail traffic, self-reported mental and physical health, noise sensitivity and the need for and access to quiet areas. No significant associations were found between self-reported hypertension and medication use and the need for and access to quiet areas. Our results were in agreement with the results of Booi and colleagues (2010) using the data of more than 800 persons gathered during a survey in Amsterdam in 2008 (Booi et al. 2010). The analyses of Booi et al. (2010) showed that people who were annoyed due to road- and air traffic, people with a bad perceived health, and noise sensitive people, had a higher need for quietness in and around their home and neighborhood. Similar to our study, Booi et al. (2010) adjusted for several potential confounders. Unfortunately, no other studies have been published investigating the association between health and the need for and access to quiet areas in people’s direct living environment. There are a few studies (Klaeboe 2001; Klaeboe et al. 2002; Berglund et al. 2004) investigating the effects of access to a quiet side at home. The Swedish project “Soundscape Support to Health“ concluded that access to a nearby quiet area promotes health: it appeared that persons with a nearby quiet area reported less annoyance, were less often disturbed during rest and relaxation, and reported less stress-related symptoms, compared to persons without a nearby quiet area. However, access to a quiet side or a nearby quiet area cannot compensate for the effects of high levels of unwanted sounds ($L_{Aeq,\ 24h}$ equal or higher than 60 dB) at the most exposed façade (Berglund et al. 2004). In an earlier study Klaeboe found that a relative good quality of a person’s direct living environment decreases the annoyance due to traffic noise (Klaeboe 2001; Klaeboe et al. 2002). Both Klaeboe and the “Soundscape Support to Health” project (Berglund et al. 2004) characterized the acoustic quality by means of objective noise measures; the latter also took into account the effects of a number of characteristics of the direct living environment.

An explorative factor analysis (not reported here) demonstrated that both the items measuring annoyance due to road- and rail traffic and dissatisfaction with access to quiet areas loaded high on the same component. Therefore, we only investigated the association between self-reported health and satisfaction with access to quiet areas. After correction for potential confounders, we found a statistically significant association between self-reported physical and mental health and satisfaction with access to quiet areas. Finally, we found a statistically significant association between the yearly-averaged cumulated noise level and satisfaction with access to quiet areas.

At the moment, no studies have been published, investigating the association between health, noise and satisfaction with access to quiet areas. However, when a person has a negative perception about his or her direct living environment, this may contribute to the total stress which this person (already) has. As a consequence, the person's (mental) health might decrease (van Kamp 1990). It is also known that objective characteristics of our living environment (such as noise levels, odor levels, provisions etc.) together with personal characteristics, determine people's perception about their direct living environment and the characteristics of that living environment (van Poll et al. 2008).

Our findings suggest that severely annoyed people, people with low self-reported mental and physical health, and noise sensitive people may benefit most from spending time in quiet areas. Since there is only a limited number of studies available from the literature, it is too early to draw general and definite conclusions. On the base of this study it cannot be ruled out that self-reported health decreases, when a person during a longer time-period is dissatisfied with access to a quiet area. More research is needed to investigate the possible health effects of spending time in areas with high acoustic quality.

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# Free field evaluation of the influence of naturalistic road and rail traffic noise on both psychological and physiological parameters

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## INTRODUCTION

The most important effects of noise extracted from the literature can be summarized as followed (Ising & Kruppa 2004; Den Boer & Schroten 2007):

- impairment of well-being reflected by the grade of annoyance
- impairment of sleep reflected by various sleep disorders
- physical stress reactions reflected by activation of the autonomic nervous system
- arterial hypertension and associated cardiovascular diseases reflected by ischemic myocardial dysfunctions.

Exposure to noise in the environment from transport sources is an increasingly prominent feature. The growing demand for air, rail and road travel means that more people are being exposed to noise, and noise exposure is increasingly being seen as an important environmental public health issue (Bluhm et al. 2004; Babisch 2006). The direct effect of sound energy on human hearing is well established and accepted (Kryter 1985; Babisch 2005). Traffic noise is presented at a level clearly below the noise level causing hearing damage, so that the aural effects can be neglected. In contrast, non-auditory effects of noise on human health are not the direct result of sound energy. Instead, these effects are the result of noise as a general stressor: thus the use of the term noise not sound: noise is unwanted sound. Non-auditory effects of noise include annoyance, mental health, sleep disturbance and physiological functions as well as having effects on cognitive outcomes such as speech communication, and cognitive performance (WHO 2000). However, these effects of noise are less well established and accepted than auditory effects.

Large parts of the population – there are estimates that it concerns about 28 % of the total population in the European Union – are constantly impaired in their quality of life, their well-being or their sleep pattern, leading to an increased health risk (WHO 2009).

The question regarding a meaningful, clinically relevant threshold of noise level caused by traffic is discussed controversially and no clear consensus has been reached to date. Also, it is not clear which parameters should be used in order to scale serious health impairment. Mostly, data either have been obtained from epidemiological field studies or from studies performed in sleeping laboratories. These laboratory based studies have the clear advantage of the presence of standardized conditions where testing results are achieved (e.g. polysomnography (PSG) (Basner et al. 2009; Griefahn et al. 2006; Ögren et al. 2008). Such a grade of standardization of testing conditions cannot be achieved in field studies where a broad range of influence factors are present, however, these studies clearly allow for better simulation of actual in-situ conditions and further allowing epidemiological studies with representative sample sizes (Öhrström 2000; Skånberg & Öhrström 2006; Miedema & Oudshoorn 2001; Miedema & Vos 2007). It is noteworthy that in all of the epidemiological studies, only questionnaires reflecting the subjective estimation of noise-induced discomfort were applied for data generation lacking any objective variables.

The subjective estimation of noise-induced discomfort can be predicted only with difficulty in general (Morgan & Dirks 1974). The informational quality of a certain sound like semantic or pragmatic aspects plus the intentional attitude of a person are highly situation-specific and therefore cannot be modeled in a reliable way. Thereby, fuzzy mathematical soft-computing methods describing the relationship between noise-induced discomfort and objective noise parameters are important to consider as reported previously (Booteldooren & Lercher 2004).

### Annoyance resulting from noise exposure

Used in connection with environmental effects, the term annoyance continues to be the subject of some ambiguities. Annoyance is in general used to mean all those negative feelings like disturbance dissatisfaction, displeasure, irritation and nuisance, but according to Guski the list may even be made longer by including somatic damage, loss of control and orientation, negative assessment of the noise source and high sound levels (Guski et al. 1999).

Noise annoyance may be conceived as an emotional process as this reaction is closely tied to the affective experience of the individual towards the noise source. Evidence of this assertion stems from investigations on aircraft noise where there has been found the existence of some correlation between the judgment of annoyance caused by aircraft noise and the fear of aircraft accidents (Leonard & Borsky 1973; Miedema & Vos 1999). In relation to this, noise annoyance may be given an attitudinal dimension as the rating of annoyance severity often depends on the acquired verbal information about the source of noise (Jonsson & Sorensen 1970). This relation noise-subject may be extended through considering the dependence of the subject to the source of noise. Hence, subjects who for instance depend economically on the source of noise tend to feel less annoyed by it than those who do not.

Traffic noise is a subject of continuous and increasing concern to people causing annoyance and associated sleep disturbances representing the direct and most relevant factors affecting health.

### Psychoacoustics in traffic noise

Psychoacoustics covers one important field of the different dimensions involved in the environmental noise evaluation process. It describes sound perception mechanisms in terms of several parameters, such as loudness, sharpness, roughness and fluctuation strength as well as further hearing-related parameters. It should be noted that psychoacoustics research is a natural progression from the research that led to the equal loudness contours, and has resulted in continuous improvements in models that predict people's perception of sounds. There are now very accurate models that can be used to predict how people for example perceive the loudness of a sound through time (Zwicker & Fastl 1999; Moore & Glasberg 1996). These models have been shown to produce levels highly correlated to people's perception of loudness of sounds in a variety of applications and yet they are getting more and more relevant when evaluating environmental noise or when trying to explain noise-annoyance dose-response relationships.

**Cardiovascular reactions**

The heart is a central organ that needs to respond quickly to external influences in order to enable fight or flight reactions. Mean heart rate, mean systolic and diastolic blood pressure as well as heart rate variability in sleeping subjects are therefore criteria for cardiovascular involvement. An indication of noise events is the prompt increase of the heart rate and change in systolic blood pressure. Carter et al. (1994) were able to show the immediate rise in heart rate following a noise event under laboratory conditions. Intermittent or periodic noises during sleep induce a biphasic heart reaction with a transient constriction of the peripheral blood vessels as well as clear changes in the electrocardiography (ECG). The biphasic response of the heart first shows a rise in heart rate followed by a decompensation reaction with a marked drop in heart rate. The vasoconstriction is ascribed to the peripheral stimulation of the sympathetic nerve triggered by auditory reflex.

Griefahn et al. (2008) found a connection between the autonomic arousals during sleep and traffic noise in their study. The response of the heart rate to traffic noise during sleep was analyzed. The extensive study took place in a laboratory under standardized conditions.

These studied cardiac effects have been solely based on laboratory data. Large epidemiologic studies that examine the cardiac risk are solely based on questioning but are however, essential for scaling the burden and identifying the meaningful limits for preventive actions against noise emissions. It is obvious that the natural surroundings and habits describe a risk better than the unfamiliar surroundings of a sleeping laboratory. Presently, the Night Noise Guidelines for Europe of the WHO (WHO 2009) demanding for a NOAEL (no observed adverse effect level) of NOAELAmax ≥ 42 dB. The heart rate reacts very sensitive to external stimuli as it is regulated by the autonomic nervous system. WHO recommends in the Night Noise Guidelines for Europe that field studies must be carried out, to better describe the influence of traffic noise regarding its potential in causing chronic disorders e.g. sleep disturbances or cardiovascular diseases.

A suitable tool to monitor changes in the depth of sleep is an actimeter. This is a simple method that can be used on several subjects simultaneously. The results obtained are in good comparison of those obtained using the PSG allowing the assessment of changes in depth of sleep at home.

## METHODOLOGY

The two main goals of the present concept are to investigate the influence of road and rail traffic noise on sleep of individuals and additionally to explore the relationship of subjective perception of test subjects with objective measured psychoacoustic and physiological parameters. The crucial point of the project is that all measurements will be done in the free field.

### Study design, measurement area and choice of test subjects

In the first step test subjects will be selected from a database consisting of test subjects having participated in our previous studies (510 persons were tested in their general health, well-being and connectivity to traffic noise) (Cik et al. 2008, 2009; Cik & Fallast 2010; Gallasch et al. 2008; Raggam et al. 2007; Wagner et al. 2010). For this study about 80 representative test subjects are intended to be investigated.

Three different areas for measurements are provided:

- Areas dominated by road traffic noise
- Areas dominated by rail traffic noise
- Areas with a combination of equivalent road and rail traffic noise
- Quiet areas with test subjects as a comparison group.

All measurements will be done at home of the test subjects and they will be performed for 5 days (4 nights) per test subject each. For the study 3 relevant time periods are intended:

- Evening: pre-sleep phase
- Night: sleep phase
- Morning: post-sleep phase.

### Free field study

For the field study different relevant parameters will be investigated and analysed. These parameters will be described in the following sub-chapters:

### Subjective data acquisition including traffic noise annoyance-rating

Collection of socio-demographic data will be done by means of a basic questionnaire at the beginning of the investigation including most important factors for test subjects in connection with environmental influences, especially traffic noise: Sex, Age, Education, Housing conditions regarding traffic noise exposure and further residential surroundings.

Electronic questionnaire:

In the "evening" and "morning" measurement periods questioning of the current traffic noise annoyance on basis of the Personal Noise Ranking Scale (PNRS) (Raggam et al. 2007; Cik et al. 2008) and with the so called „experience sampling method" (time near seizing of experiences, feelings and behavior) (Larson & Csikszentmihalyi 1983; Hektner et al., 2006) will be developed and done. The PNRS was assigned as an 11-graded interval scale, ranges were defined from ''less annoying'' to ''very annoying'' and it is based on the ICBEN-scaling (ISO 15666, 2003). In individual investigation areas the test subjects evaluate their hourly annoyance by rail and/or road traffic noise and also respond the questions of the experience sampling method with help of portable data recording equipment (PDA) in the measurement periods on the days of investigation. In addition to electronic questioning a morning and an evening questionnaire will be designed:

- Morning questionnaire including data of the past night: sleep times, sleep quality and night disturbances
- Evening questionnaire including data of residence times at home, noise disturbance by day and work and acceptance of the measurement instruments.

## Objective acoustical measurement

Goal of the acoustical measurements is to achieve a time-synchronicity between result of the electronic questionnaire (traffic noise annoyance-rating, experiences, feelings and behavior) with PDA and acoustical parameters including sound pressure level and psychoacoustics reflecting the total quantity of the test subject's acoustic load.

Relevant factors for the acoustical measurement:

- Measurements (recordings) of current existing sound emissions to get a realistic illustration of the traffic noise exposure of each test subject in the investigated area

- Selection of measuring points in the natural residential surroundings of the test subjects which will be an individual adjustment at the investigated site (max. 5 measuring points):
  - Outside
  - Inside

- For audio-recording of traffic and environmental sounds two different technologies will be applied:
  - Binaural dummy head recordings
  - Monaural sound pressure level meter recordings

  The recordings will be done during all three time periods and statistically correlated with the collected subjective and physiological data. Especially current high sound pressure level can have a strong influence on the traffic noise annoyance-rating and these data is only with difficulty verifiable.

- Analysis of all sound recording data will be done by post-processing:
  - Monaural recordings: Calculation of all norm-parameters in combination with the sound pressure level (ÖNORM S 5004: 2008 12 01)
  - Binaural recordings: Calculation of all relevant psychoacoustic parameters (ÖNORM S 5006:1995 10 01; Aures 1985; Terhardt et al. 1982; Zwicker & Fastl 1999) and of all norm-parameters (ÖNORM S 5004:2008 12 01) in combination with the sound pressure level.
  - During the project research will also focus on possible new relevant psychoacoustic parameters.

- Data collection of traffic volume in the investigated time period as comparison

- Collected data will be used to establish environmental noise maps and will be compared to those already existing, especially to those reported in international studies.

### Measuring physiological parameters

Heart rate has always been measured using an ECG in prior laboratory studies. This is certainly the gold standard, as the leads allow for an exact beat to beat analysis and therefore also the variability in heart rate can be investigated (Basner et al. 2009). Field studies differ significantly where the study subjects sleep in familiar surroundings in their own house not allowing the use of ECGs. In addition, being able to reliable discriminate significant relevant variables, epidemiological studies require a much larger number of study subjects.

Polar® watches were developed for professional sports and multi-athletes in order to measure their achievement potential and to increase it through heart rate controlled training. For this study, heart rate measurements are necessary which are as precise as ECGs. The measurement and interpretation of heart rate variability (HRV) allows conclusions concerning the adaptability of the heart to internal and external stimuli. The new generation of Polar® watches allows for a beat to beat measurement, and the sensitivity is high enough to permit its use in epidemiological studies.

Body movements will be registered by using a wrist-actigraph, specifically type MicroMini-Motionlogger® Actigraph from Ambulatory Monitoring Inc. The actigraph is based on an acceleration sensor that translates movements to a numeric presentation that is stored in a memory.

Sleep disturbances, defined both as awakenings or changes in depth of sleep, are frequently associated with traffic noise and are an important criterion in defining limits for noise pollution. Polysomnography is the gold standard for detecting of sleep disturbances, by using the EEG (Basner et al. 2009). The above-mentioned method is not suitable for on-site epidemiological studies. The setup and handling of the instruments is too complicated for on-site use, so that a large number of subjects cannot be studied with regard to the different stressors in the environment.

The term "Actigraphy" refers to methods using computerized wristwatch-size devices (generally placed on the wrist, but also on the ankle or trunk) to record the movement it undergoes. Collected data are displayed on a computer and analyzed for change in rhythm parameters that in turn provide an estimate on wake-sleep parameters such as total sleep time, percent of time spent asleep, total wake time, percent of time spent awake, number of awakenings and number of movements.

Actigraphy provides a useful, cost-effective, non-invasive and portable method for assessing specific sleep disorders. The present review is an amalgam of current knowledge with proposed clinical application and for research of actigraphy (Tahmasian et al. 2010).

The physiological measurements will be done during the night period for each test subject in the investigated area.

### Statistical analysis

Data of statistical analyses from former laboratory studies realized at Graz University of Technology show significant results and serve as basis for the project in which extended analyses will be done (Cik et al. 2008, 2009; Cik & Fallast 2010; Gallasch et al. 2008; Raggam et al. 2007; Wagner et al. 2010).

Following advanced statistical analysis will be performed:

- Descriptive analysis of the subjective, physiological and objective data
- Correlation of the results obtained from subjective and physiological data with results obtained by objective acoustical measurements and calculations
- Regression and multiple regression analysis between

  - subjective data and objective acoustical measurements
  - subjective data and physiological measurements
  - and objective acoustical measurements and physiological data
- Comparisons of field study results with results obtained in the laboratory studies.

## CONCLUSION

The direct effects of sound energy on human hearing are well established and accepted but previous research about the effects of noise exposure on medical parameters has been carried out mainly under laboratory conditions. Such test arrangements are not representative of the real impacts on humans, especially at night during sleep phases.

The two main objectives of this designed project are to investigate the influence of road and rail traffic noise on human sleep patterns and additionally to explore the relationship of subjective perception of test subjects with objective measured psychoacoustic and physiological parameters. The crucial point of the project is that all measurements will be done in the free field with real-life situations. The goal of acoustical measurements is to achieve a time-synchronicity between the results of the electronic questionnaire (traffic noise annoyance-rating, experiences, feelings and behavior) and acoustical parameters including sound pressure level and psychoacoustics reflecting the total quantity and quality of the test subject's acoustic exposure.

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# The effects of noise on biochemical parameters using rat's hearts

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## INTRODUCTION

Noise pollution is becoming increasingly pervasive especially in industrial countries. Prevalence of noise is implicated in various illness of human and it is responsible for increased morbidity associated with modern life style. There are several non-auditory physiological effects of noise exposure including hypertension, ischemic heart disease as well as disturbed serum lipid, triglycerides, platelet count, plasma viscosity, glucose and reduced motor efficiency. This study is aimed to investigate the effect of noise on plasma blood glucose concentration and lipid profile in the study groups as compared to control.

## METHODS

The rats were divided into four groups and they include exposure to noise of intensity 80-100 dBA on duration of 12 hours exposure (acute effect), 8 hours daily for 20 days (chronic effect), 20 days into 3 days exposure and 2 days without 8 hours per day (intermittent effect) and the control group.

## RESULTS

Plasma glucose was significantly increased in its concentration for the acute and chronic continuous groups as compared to control. The cholesterol, triglycerides (TG) and high density lipoprotein (HDL) had no significant difference compared to control in the case of acute noise exposure although there is a significant elevation in the chronic continuous group. HDL level revealed significant elevation in case of chronic continuous and intermittent noise exposure ($p<0.05$) when compared to control group.

## CONCLUSION

High intensity noise may trigger the negative impact to our biochemical parameters, especially in long continuous noise exposure setting.

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# The effects of noise on cardiovascular parameters using isolated rat's hearts

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## INTRODUCTION AND OBJECTIVES

Prolonged exposure to loud noise can have lasting adverse effects on health. Noise damages not just the auditory system but also systematically by activating the sympathetic nervous and hormonal systems. This will lead to changes in blood pressure, heart rate, and other circulatory factors, which consequently can result in many cardiovascular diseases. The present study was undertaken to evaluate the effect of acute and chronic high intensity noise on the isolated hearts of rats using the Langendorff apparatus by determining the effect of noise on the coronary perfusion pressure (CPP), heart rate (HR) and left ventricular diastolic pressure (LVDP).

## METHODS

The rats were divided into four groups and they include exposure to noise of intensity 80-100 dBA on duration of 12 hours exposure (acute effect), 8 hours daily for 20 days (chronic effect), 20 days into 3 days exposure and 2 days without 8 hours per day (intermittent effect) and the control group.

## RESULTS

Noise of 80-100 dBA was found to cause significant increase in CPP, LVDP and HR ($p<0.05$) for acute and both chronic groups versus control. On other hand there were no significant differences of the CPP,LVDP and HR between the chronic intermittent group with the chronic continuous noise exposure group of the study.

## CONCLUSION

The present study determined that high intensity noise may have an adverse effect on cardiovascular functions and thus noise exposure should be well monitored.

# The influence of noise on performance and behavior – 3 year update

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## INTRODUCTION

The most recent ICBEN review of this field (Clark 2008) highlighted the focus of the field on noise effects on children's performance and suggested the need for further evidence of exposure-effect associations between noise exposure and performance, as well as further assessment of the associations between classroom acoustics, speech intelligibility, noise effects on performance, and on developing a greater understanding of the mechanisms underlying noise effects on cognition. This paper highlights some of the recent developments in the field of noise effects on performance and behavior over the past three years. It is not a systematic review but aims to highlight current areas of research, recent findings in the field, and ongoing research. The paper is divided into two sections: the first section summarises developments in field studies of noise effects on children's cognitive performance; the second section summarises recent developments in experimental studies of auditory distraction.

## FIELD STUDIES OF THE EFFECTS OF NOISE ON COGNITIVE PERFORMANCE

The effect of environmental noise exposure on children's cognitive performance and learning has been researched since the early 1970s. Typically, in more recent years, the effect of chronic noise exposure on children's cognition has been examined by methodologically robust epidemiological studies, whilst the effect of acute noise exposure has been examined in experimental, laboratory studies. It has been suggested that children may be especially vulnerable to effects of environmental noise and that exposure during critical periods of learning at school could potentially impair development and have a lifelong effect on educational attainment.

### Epidemiological studies

Overall, evidence for the effects of noise on children's cognition has strengthened in recent years (Evans & Hygge 2007). Several studies have demonstrated that children exposed to chronic aircraft noise exposure at school have poorer reading ability, memory, and school performance on nationally standardised tests than children who are not exposed (Bronzaft 1981; Bronzaft & McCarthy 1975; Clark et al. 2006; Cohen et al. 1973; Eagan et al. 2004; Evans et al. 1995; Evans & Maxwell 1997; Green et al. 1982; Haines et al. 2001a, b, 2002; Lukas et al. 1981). Most research has been carried out in primary school children aged 5 to 12 years. The evidence is predominantly cross-sectional but has also been confirmed with longitudinal data from before and after studies assessing naturalistic changes in noise exposure via insulation programs or airport closures. However, such effects are not uniform across all cognitive tasks (Cohen et al. 1986; Evans & Lepore 1993; Evans et al. 1991). Evidence from longitudinal studies is beginning to emerge, and studies have started to examine exposure-effect relationships, to identify thresholds for noise effects on health and cognition which can be used to inform guidelines for noise exposure. The following section describes the findings of epidemiological studies published in recent years which build on this existing knowledge base.

### The RANCH Project

The RANCH project (Road Traffic Noise and Aircraft Noise Exposure and Children's Cognition and Health), the largest study of noise and children's cognition undertaken to date, examined the effects of aircraft noise and road traffic noise exposure at primary school on the cognitive performance of 2,844 9-10 year old children attending 89 schools around Heathrow (London), Schiphol (Amsterdam), and Barajas (Madrid) airports. The study found linear exposure-effect relationships between aircraft noise exposure at school and children's reading comprehension and recognition memory (Clark et al. 2006; Stansfeld et al. 2005). A further paper reports different effects of road traffic noise and aircraft noise on a range of episodic memory tasks, suggesting that these types of noise impact certain aspects of children's episodic memory (Matheson et al. 2010). The study found that whilst aircraft noise exposure at school had a significant effect on recognition memory, there was no significant effect of aircraft noise on cued recall (a type of long-term memory) or on prospective memory (memory for a planned action or intention e.g. remembering to post a letter). Contrastingly, road traffic noise exposure at school was significantly associated with improved performance on cued recall in a linear exposure-effect relationship: this finding was unexpected and needs replicating in further samples before conclusions can be drawn. Road traffic noise exposure was not associated with prospective memory or recognition memory. The paper concludes that the mixed and unexpected results highlight the need for more theoretical and empirical research to ascertain a more complete understanding of the impacts of noise on children's episodic memory. There are currently ongoing studies using the RANCH methodology taking place in South Africa and Italy to further examine the effects of aircraft noise on children's learning, as well as a follow-up study of the UK cohort in secondary school to see if primary school aircraft noise exposure has an effect on reading comprehension in later years (Clark et al. 2011).

A sub-study of the RANCH project in the Netherlands investigated the effects of aircraft and road traffic noise exposure on cognitive performance of primary school children assessed using the Neurobehavioral Evaluation System (NES) (van Kempen et al. 2010). Overall, the analyses suggest that performance on simple tasks was less susceptible to the effects of chronic noise exposure at school than more complex tasks assessed using the NES.

### The FICAN study

The Federal Interagency Committee on Aviation Noise (FICAN) recently funded a novel pilot study which assessed the relationship between aircraft noise reduction and standardised test scores (Eagan et al. 2004; FICAN 2007). The study evaluated whether abrupt aircraft noise reduction within classrooms, caused either by airport closure or newly implemented sound insulation, was associated with improvements in test scores, in 35 public schools near three US airports in Illinois and Texas. This study is one of the only recent studies to examine the effectiveness of school sound insulation programs as few intervention studies have been carried out (Bronzaft

1981; Cohen et al. 1981). Overall, this study found some evidence for effects of aircraft noise reduction and improved test results, although it must be acknowledged that some associations were null and some associations were not in the direction hypothesised. This was a pilot study and the authors stress that the airports and schools selected for the study may not be representative; that further, larger studies are required. A larger scale study of this nature is currently ongoing funded by the Aviation Cooperative Research Program.

### Mechanisms

Several pathways for effects of chronic noise exposure on children's cognition have been suggested including teacher and pupil frustration (Evans & Lepore 1993), learned helplessness (Evans & Stecker 2004), impaired attention (Cohen et al. 1973; Evans & Lepore 1993), increased arousal (Yerkes & Dodson 1908), and indiscriminate filtering out of noise during cognitive activities resulting in loss of attention (Cohen et al. 1986). However, experimental evidence suggests that noise effects on cognitive performance are not mediated by impairment of attention (Hygge et al. 2003). Noise causes annoyance, especially if an individual feels their activities are being disturbed or if it causes difficulties with communication and in some individuals this annoyance may lead to stress responses. However, at present there is little evidence to directly support the annoyance pathway as a mechanism for effects on cognition. The RANCH study found that the effect of aircraft noise on children's reading comprehension was not explained by noise annoyance (Clark et al. 2006).

Another pathway for the effect of noise on cognition is that of sleep disturbance caused by noise exposure at home. Sleep disturbance can impact on well-being causing annoyance, irritation, low mood, fatigue, and impaired task performance (HCN 2004). Few studies have examined sleep disturbance as a mediator of noise effects on cognitive performance and most previous studies have not differentiated day- and night-time noise exposure. A recent secondary analysis of night-time noise exposure in the cross-sectional Munich and RANCH study datasets found that self-reported sleep disturbance did not mediate the association of aircraft noise exposure and cognitive impairment in children (Stansfeld et al. 2011). This paper also reports that for the RANCH sample, whilst night-time aircraft noise exposure at the child's home was associated with impaired reading comprehension and recognition memory, night-time aircraft noise had no additional effect on these cognitive outcomes, once day-time noise exposure had been taken into account. Whilst day-time and night-time aircraft noise exposure were highly correlated in the RANCH data, these findings suggest that the school should be the main focus for the protection of children against the effects of aircraft noise on school performance (Stansfeld et al. 2010).

### Classroom acoustics & children's learning

Recent years have seen research begin to explore the link between classroom acoustics and children's learning outcomes (Astolfi & Pellerey 2008; Bradley & Sato 2008; de Oliveira Nunes & Sattler 2006; Dockrell & Shield 2004, 2006; Sato & Bradley 2008; Shield & Dockrell 2004, 2008). These studies typically focus upon noise interference with verbal communication as the mechanism for the effect: some studies simply describe the acoustic characteristics of classrooms, some specifically assess speech intelligibility, and a few relate acoustic conditions to performance outcomes such as individually completed cognitive tests, as well as nationally standardised tests (Shield & Dockrell 2008). This work on primary school children, is currently being extended in the ISESS project (Identifying a Sound Environment for Secondary Schools) – a three year project investigating the effects on teaching and learning of different acoustic designs within secondary schools and classrooms in the UK.

EXPERIMENTAL STUDIES OF THE EFFECTS OF NOISE ON COGNITIVE PERFORMANCE

Four lines of experimental research have flourished during the past three years: (1) functional differences in varieties of auditory distraction, (2) semantic auditory distraction, (3) individual differences in susceptibility to auditory distraction, and (4) the role of cognitive control to the effects of noise on understanding and memory of target speech materials. The general conclusions from these lines of research are reviewed below.

**Functional differences in varieties of auditory distraction**

Serial short-term memory of visually presented items is impaired by the mere presence of background sound, at least when the sound changes acoustically. For instance, the sound sequence "k l m v r q c" is more distracting to serial recall than is the sound sequence "c c c c c c c". This finding is called the changing-state effect (Jones & Macken 1993). Furthermore, an auditory event that stands out or deviates from the recent auditory past, such as the sound "m" in the sound sequence "c c c m c c c", disrupts serial recall. This phenomenon is known as the deviation effect (Hughes et al. 2005, 2007; Lange 2005). Whether or not these two effects are caused by the same mechanism has long since been subject to debate. However, Jones, Hughes, and colleagues (Hughes et al. 2007; Jones et al. 2010; Perham et al. 2007) recently ran a series of experiments with the purpose to disentangle the functional properties of these two effects and a number of findings suggest that changing-state and deviating sounds have different effects on cognitive performance. First, a deviating sound disrupts performance on tasks that do not require any order processing whereas changing-state sound sequences do not (Hughes et al. 2007; Jones & Macken 1993; Perham et al. 2007); second, the changing-state effect and the deviation effect do not interact in their disruption of serial recall (Hughes et al. 2007); and third, the deviation effect is absent when the deviant is presented during a retention interval between encoding and retrieval of the memory items, whereas the changing-state effect is still present when the sound is presented during the retention interval (Hughes et al. 2005).

Based in part on the series of results reviewed above, Hughes et al. (2007) have proposed a duplex-mechanism account of auditory distraction whereby the changing-state effect is the result of interference between order processes whereas the deviation effect is caused by attentional capture. Sound, it seems, can impair cognitive performance in two functionally different ways: Either by interfering with the deliberate processes that are engaged in the focal task or by interrupting the execution of the processes. This general conclusion has, however, been met with some noteworthy criticism. For instance, Bell et al. (2010) measured event-related brain potentials during exposure to changing-state (e.g. "norm", "bug", "tausch", "eid" etc.) and steady-state (e.g. "bug", "bug", "bug", "bug", etc.) sound sequences in a typical visual-verbal serial recall setting. The results revealed that changing-state sound elicits neural responses typically associated with attentional capture. The authors concluded that changing-state sound disrupts serial recall by capturing attention and argued against the duplex-mechanism account of auditory distraction.

**Semantic auditory distraction**

The role played by the semantic properties of speech has until recently been somewhat delusive. Older studies have provided conflicting results, some suggesting that disruption is larger when task-irrelevant speech is semantically related to the target material (e.g. Neely & LeCompte 1999; Oswald et al. 2000) whereas other studies suggest that disruption is solely a result of the physical properties of the sound (e.g. Buchner et al.1996; Tremblay et al. 2000). Recently, however, Marsh et al. (2008, 2009) have shown that when the focal task requires semantic processing (e.g. retrieving items on the basis of their meaning) the semanticity of irrelevant speech is more disruptive than the sound's acoustic properties. Marsh and colleagues have employed an experimental paradigm whereby each experimental trial involves visually-presented to-be-recalled exemplars that are members of the same semantic category (e.g. Fruit). During some trials, the participants are also presented with to-be-ignored spoken words that are either taken from the same semantic category as the to-be-recalled items (e.g. other Fruit) or from a different semantic category (e.g. Tools). In this paradigm, recall is poorer in the semantically-related condition, but only when the participants are allowed to recall the items in free order. This finding is called the between-sequence semantic similarity effect. Also, the participants tend to recall the spoken words by mistake, at least when the spoken words are semantically related to the target words. Semantic auditory distraction thus embodies a between-sequence semantic similarity effect and promotion of intrusions from non-target items by speech semantically related to the to-be-recalled items. Marsh and colleagues have interpreted these findings within an *interference-by-process* approach to auditory distraction, similar to that applied to the changing-state effect (Marsh et al. 2008, 2009). They explain semantic auditory distraction in terms of deliberate inhibition of non-target competitors activated by speech which spreads to target items and thus impair recall and in terms of a breakdown of source monitoring.

Based upon the work by Marsh and colleagues reviewed above, Sörqvist et al. (2010a, b) run a series of experiments to investigate hemispheric asymmetries in semantic auditory distraction. They manipulated the sounds' presentation source and found that the magnitude of semantic auditory distraction is larger when the speech material is presented to the right ear only in comparison with when it is presented to the left ear only. This finding was coined a right-ear disadvantage and appears to be a result of the left hemisphere's dominant role in semantic processing. The left hemisphere's specialisation in linguistic processing turns into a disadvantage when the focal task requires visual-semantic processing and the speech sound is to be deliberately ignored.

**Individual differences in susceptibility to auditory distraction**

The reason why people differ in susceptibility to auditory distraction has also been debated during the past three years. This debate has mainly concerned whether auditory distraction can be overruled by cognitive control or not. In support of a role for cognitive control in auditory distraction, Sörqvist and colleagues (Sörqvist 2010a, b, c; Sörqvist et al. 2010a, b) have shown that individuals with high working memory capacity (WMC) are generally less susceptible to auditory distraction. This general conclusion is consistent with the notion that older individuals, who are known to be more lenient in cognitive control generally, are more susceptible to the effects of speech on prose memory (Bell et al. 2008). However, the conclusion is qualified by an intriguing finding. High-WMC individuals are less susceptible to the deviation effect, but not to the changing-state effect (Sörqvist 2010b). It appears, therefore, as if some but not all types of auditory distraction can be overruled by cognitive control.

What, then, underlies individual differences in susceptibility to the changing-state effect? To address this question, Macken et al. (2009) asked participants to listen to pairs of sound-patterns and requested them to judge whether or not the two patterns in each pair were the same. The authors argued that the pattern-matching task measures the ability to automatically process order information in sound sequences. Later, the participants performed a serial recall task for the authors to obtain a measure of the changing-state effect, and the results revealed that the participants who performed *well* on the pattern-matching task were the ones *most* susceptible to the changing-state effect. Based on these findings, the authors concluded that the magnitude of the changing-state effect is a function of the efficiency whereby people process acoustical change in sound. Taken together with the other studies reviewed above, these results provide further evidence in support of the duplex-mechanism account of auditory distraction. The deviation effect appears to be a result of captured attention which can be overruled by top-down control, whereas the changing-state effect appears to be a result of perceptual, automatic processes which cannot be overruled by cognitive control.

### Effects of noise on understanding and memory of speech material

Thus far all studies reviewed in this section above concern cross-modal auditory distraction. In these situations, all sound is irrelevant to the focal task. However, many situations require us to listen to sound. In schools, for instance, pupils learn from spoken lectures. Noisy school environments compromise speech perception and in those situations pupils need to filter the target speech signal from the masking sound. Here we will shortly review some recent advances on such within-modal auditory distraction situations.

In a series of experiments, Kjellberg, Ljung and colleagues have shown that low signal-to-noise ratio (approximately +5 dBA) impairs memory of spoken materials, in comparison with high signal-to-noise ratio (approximately +27 dBA), even when the low signal-to-noise ratio does not impair speech comprehension. This general conclusion has been demonstrated for memory of spoken word lists (Kjellberg et al. 2008) and for memory of spoken lectures (Ljung et al. 2009). A similar pattern of results have also been found when reverberation, rather than masking noise, has been manipulated. Long reverberation time of the target speech sound impairs memory of the spoken words, relative to a short reverberation time, even when speech comprehension is unaffected (Ljung & Kjellberg 2009; Ljung et al. 2009).

It appears, however, as if the negative impact of noise on speech comprehension and memory of spoken materials can be overruled by cognitive control (Rönnberg et al. 2008, 2010). For instance, people's memory of spoken discourse is impaired if the target speech signal is masked by another voice in comparison with when the masking sound is a semantically meaningless speech-like sound, but this effect is smaller to individuals with high working memory capacity (Sörqvist & Rönnberg 2011).

**Summary of experimental studies**

The evidence accumulated during the past three years indicate that we do have, at least, two functionally distinct forms of auditory distraction. Noise can distract cognition either by creating a conflict between processes or by interrupting the execution of the task. This conclusion receives support both from pure experimental studies and from individual differences studies that have aimed to elucidate the role for cognitive control in auditory distraction. It seems also as if the long lasting research question "Is speech special?" has received a final answer. The answer is "yes, at least sometimes". Speech, as opposed to sound without semantic content, is enforced with disruptive power over and beyond the acoustic properties of the sound, at least when the focal task requires semantic processes. Finally, we have seen some intriguing results suggesting that masking noise can impair memory of spoken information even when speech comprehension is at acceptable levels. This finding highlights the importance of memory when evaluating classroom acoustics. Classrooms should perhaps be evaluated on the basis of a memory criterion rather than a speech comprehension criterion.

## CONCLUSIONS

The European Network on Noise and Health (ENNAH) recently published recommendations for future and new research needs that aim to tackle gaps in knowledge in the field of noise effects on cognition (see www.ennah.eu). These recommendations suggest that to understand the causal pathways between aircraft noise exposure and cognition, and design preventive interventions there is a need to study the associations longitudinally. Few longitudinal studies have examined the effects of persistent aircraft noise exposure throughout the child's education: such studies remain of prime policy importance. Another area where knowledge is lacking concerns the question of what can be done to reduce noise induced learning impairments: there has been little research testing whether sound insulation of classrooms might lessen the effects of aircraft noise on children's learning. A further recommendation is to examine how aircraft noise exposure may interact with other environmental stressors that co-occur with airport operations such as air pollution or road traffic noise. It is possible that the combined exposure to these transport related stressors could interact and increase their single effects. It was also suggested that future studies should incorporate a range of additional noise metrics such as the number of noise events and peak sound events and examine their associations with children's cognitive performance to explore noise characterisation in more detail. Finally, whilst recent evidence of exposure-effect relationships between aircraft noise exposure and children's cognition has provided knowledge about thresholds for effects, further examination of exposure-effect relationships in different contexts, for different samples and vulnerable groups, and for different noise metrics remains a research priority.

We would like to take the opportunity to request one line of laboratory studies that could prove fruitful in the future. Laboratory studies could investigate how the spatial distribution of the irrelevant sound sources and the target materials influence auditory distraction. This line of study could further elucidate functional differences between various forms of auditory distraction and how the brain's hemispheres process sound. Moreover, knowledge in this realm would enhance our understanding of how to build classrooms and offices with optimal sound distribution.

The previous review of the field (Clark 2008) highlighted the lack of studies examining noise effects on human behavior. At this time, there remains a lack of studies of noise effects on behavior. A recent systematic review (Hughes et al. 2011) highlighted studies which have found that loud noise exposure in bars and nightclubs is associated both with increased aggressive behavior as well as with intoxication. Such studies illustrate links between noise exposure and behavior that have important public health implications. The field needs to identify and explore noise effects on behavior in more detail.

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## Noise in secondary schools: pupils' perceptions and performance

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ABSTRACT

A project is currently being undertaken to investigate the acoustic environment in secondary schools, student and staff perceptions of their aural environment and pupil learning and behavior under different acoustic conditions. This paper presents data on the pupils' views of their learning environments and the ways in which noise sources differentially affect performance across cognitive tasks and vocabulary acquisition. Methodological confounds in drawing reliable and generalizable findings about performance in different acoustic conditions are considered. Implications for teaching and learning in secondary school classrooms are addressed.

# Noise effects on children's cognition - WHO work on noise, Burden of Disease (BoD) and Disability-Adjusted Life Years (DALY)

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## INTRODUCTION

It has been suspected for many years that children's learning and memory are negatively affected by noise. Over 20 studies have shown negative effects of noise on reading and memory in children (Evans & Hygge 2007; Evans & Lepore 1993): epidemiological studies report effects of chronic noise exposure and experimental studies report acute noise exposure. Tasks affected are those involving central processing and language, such as reading comprehension, memory and attention (Haines 2001a, 2001b, Evans & Maxwell 1997; Cohen et al. 1973). Exposure during critical periods of learning at school could potentially impair development and have a lifelong effect on educational attainment.

Evidence from recent well-controlled epidemiological studies with representative samples of children has also made it possible to start to quantify the magnitude of noise-induced impairment on children's cognition and identify the relative contribution of different sources of noise. Such quantifications, albeit initially crude, will in the long run help to estimate and quantify how much cognitive development individual children could be expected to lose because of noise, and the economic impact of this for learning in schools. In turn, such estimates will be also of value for making projections on the societal level, including political decision about any sociodemographic redistribution of noise exposure.

### Definition of outcome

Cognitive impairment is not an outcome of a clinical diagnosis. It is therefore not possible to derive a conventional exposure–risk relationship suitable for calculating burden of disease. Lopez et al. (2006) defined cognitive impairment as "delayed psychomotor development and impaired performance in language skills, motor skills, and coordination equivalent to a 5- to 10-point deficit in IQ". Contemporaneous cognitive deficit is defined as "reduction in cognitive ability in school-age children, which occurs only while infection persists".

These definitions are not helpful and not readily applicable to the studies reported on noise and cognition in children. None of the studies has explicitly employed IQ as an end-point and the confining of any reduction in cognitive ability to the duration of the noise exposure is too restrictive. Therefore, our case definition of noise related cognitive impairment is:

> Reduction in cognitive ability in school-age children that occurs while the noise exposure persists and will persist for some time after the cessation of the noise exposure.

### Summary of evidence linking noise and cognitive impairment in children

The extent to which noise impairs cognition, particularly in children, has been studied with both experimental and epidemiological designs. The epidemiological studies report effects of chronic noise exposure and the experimental studies of acute noise exposure. The studies relevant to children's cognition are not many and do not always meet strict methodological criteria. Nevertheless, there are three recent studies that meet basic methodological quality criteria and are also comparable with each other in terms of the cognitive functions measured.

One of the most compelling studies in this field is the naturally occurring longitudinal quasi-experiment reported by Evans and colleagues, examining the effect of the relocation of Munich airport on children's (9–10 years, N = 326) health and cognition (Evans et al.1995, 1998; Hygge et al. 2002). In 1992, the old Munich airport closed and was relocated. Prior to relocation, high noise exposure was associated with deficits in long-term memory and reading comprehension. Two years after the closure of the airport, these deficits disappeared, indicating that effects of noise on cognition may be reversible if exposure ceases. Most convincing was the finding that deficits in the very same memory and reading comprehension tasks developed over a two-year follow-up in children who became newly exposed to noise near the new airport.

The recent large-scale RANCH study, which compared the effect of road traffic and aircraft noise on children's (9–10 years, *N* = 2,844) cognitive performance in the Netherlands, Spain and the United Kingdom, found a linear exposure–effect relationship between long-term exposure to aircraft noise and impaired reading comprehension and recognition memory, after taking a range of socioeconomic and confounding factors into account (Stansfeld et al. 2005). No associations were observed between long-term road traffic noise exposure and cognition, with the exception of episodic memory, which surprisingly showed better performance in high road traffic noise areas. Neither aircraft noise nor road traffic noise affected attention or working memory.

A study of ambient noise exposure (predominantly road and rail sources) of fourth-grade children living in the Tyrol mountain region (Lercher et al. 2003) compared three cognitive measures for schoolchildren (mean age 9–7 years, *N* = 123) exposed to 46 or 62 dBA $L_{dn}$. The two sociodemographically homogeneous samples differed only in their noise exposure range (M = 46.1 $L_{dn}$ vs M = 62 $L_{dn}$). Long-term noise exposure was significantly related to both intentional and incidental memory. The improvement in cognitive performance in the quieter group was estimated at 0.5 % (recall prose and recognition) to 1 % (free recall) per dB. The authors note that the magnitude of the effects shown was smaller than those uncovered in earlier airport noise studies.

Both the RANCH and Tyrol studies indicate that aircraft noise may be worse for cognition than road traffic noise. For aircraft noise, exposure evidence from the Munich study seems to indicate that $L_{Aeq}$ = 60 dB may be a dividing line, but the RANCH study results suggest more of a linear association between aircraft noise exposure and impairment of reading comprehension. For ambient road and rail noise, the Tyrol study suggests that effects occur around $L_{dn}$ = 60 dB.

Other field studies of children have had some methodological limitations, which make them less relevant as evidence. For example, the testing of cognitive capacities took place in noisy conditions for the noise-exposed and in quieter conditions for the children in the control groups. Testing in silent conditions would have been preferred, in order to compare the noise effect on memory and learning between exposure and control groups (Bronzaft 1981; Bronzaft & McCarthy 1975; Green et al. 1982; Haines et. al. 2002; Lukas et al. 1981). Also, for some studies, the socio-demographic variables and different reading curricula between the schools were not fully adjusted or controlled for.

METHODS

**Exposure–response relationship**

Only the Tyrol study (Lercher et al. 2003) has used the noise indicator $L_{dn}$. The Munich study used $L_{eq24}$ and the RANCH study predominantly used $L_{eq16}$. The $L_{dn}$ and $L_{eq}$ metrics are not directly equivalent: $L_{dn}$ is always equal to or larger than $L_{eq}$, with the following differences between $L_{dn}$ and $L_{eq}$ (T. Gjestland, personal communication, 2006):

- evenly distributed traffic flow, + 6.4 dB
- evenly distributed 07:00–22:00, no night traffic, + 1.9 dB
- 10 % of traffic during 22:00–07:00, + 2.9 dB.

Although it is not clear which noise metric is the most adequate, $L_{dn}$, which combines daytime and nighttime exposure, was here chosen for examining the effects of aircraft noise on cognition. However, this issue may be more complicated for other noise sources.

Figure 1 shows the exposure–response curves from the different epidemiological studies. This can be summarized in quantitative terms. For the field studies in 1, memory recall and reading have average slopes of around 2 % per $L_{dn}$, as calculated by the mean of the slopes of the six lines. Thus, for recall and reading, it is expected that a reduction of the chronic noise level by 5 $L_{dn}$ would result in improved performance by 10 %. As noted above, the only available road traffic noise study (Lercher et al. 2003) had a less steep slope. The fact that we do not have much data from road traffic noise exposure set a limit to the generality of our conclusion, but the results of studies on aircraft noise, albeit few, are nevertheless consistent.

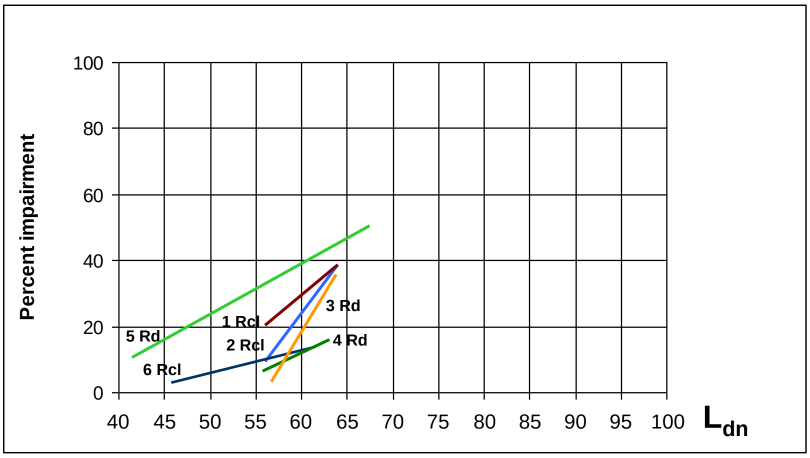


**Figure 1:** Exposure-response curves from different epidemiological studies. Rd = reading, Rcl = memory, recall. 1-4 = Hygge et al. (2002), 5 = Stansfeld et al. (2005), 6 = Lercher et al. (2003).

To obtain the exposure–response relationship, we need to use the information above to determine an approximate curve. Assuming that 100 % of those exposed to noise are cognitively affected at the very high noise levels, e.g. 95 $L_{dn}$, and that none are affected at a safely low level, e.g. 50 $L_{dn}$, a straight line (linear accumulation) connecting these two points, as was done in Fig. 1, can be used a basis for approximations. Note that such a straight line is an underestimation of the real effect. For theoretical reasons, based on an assumed underlying normal distribution, the true curve should have the same sigmoidal function form as the curve in Fig. 2. Within the noise exposure bracket 55–65 $L_{dn,}$ the straight line and the solid line sigmoidal distribution agree on approximately 20 % impairment. In the bracket 65–75 $L_{dn,}$ the number should be in the range of 45–50 % and above 75 $L_{dn}$ in the range of 70–85 %.

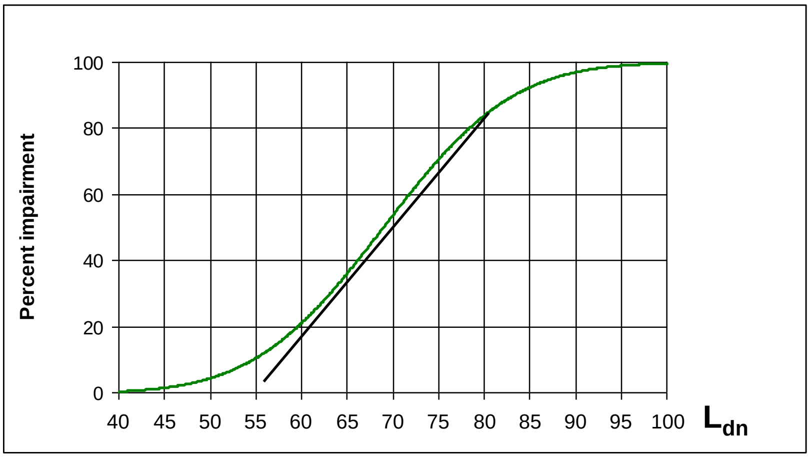


**Figure 2:** A sigmoidal S-function from the normal distribution and a straight line approximation as in Figure 1. Note that within the noise exposure bracket < 60 $L_{dn,}$ the straight line underestimates the impairment

## Disability weight

Lopez et al. (2006) suggested DWs for different cognitive impairments ranging from 0.468 (e.g. Japanese encephalitis) or 0.024 (e.g. as a result of iron deficiency anaemia). Contemporaneous cognitive deficit was given a DW of 0.006. Thus, this is a very conservative choice to go with the definition of contemporaneous cognitive deficit and a DW of 0.006 in estimates of the noise-related impairment of children's cognition.

There would be no mortality due to cognitive impairment, so estimation of YLD per year will be sufficient to estimate the total DALYs.

## EBD calculations - Assumptions

*Disability weight*

Knowing the approximate distribution across age groups of the population in a country, assuming a certain DW weight (0.006) and making assumptions about how many percent of the children are fully affected in the noise exposure brackets, a tentative burden of disease from cognitive impairment stemming from noise exposure in children aged 7–19 years can be calculated and expanded to the WHO EUR A epidemiological sub-region (Lopez et al. 2006). This is done in Table 1.

*No noise after-effect*

Note that the calculations rest on the assumption that the noise effects are there only when people are exposed. There is no assumption made that the inflicted noise-induced disability lasts longer than the noise exposure. It would not be unreasonable to set a case also for lasting cognitive effects of noise also after the cessation of exposure, but that has explicitly not been done here.

*Percentage of noise exposed children*

In Table 1 the distribution of the population across the age groups is taken from Swedish population data in late 2004 was taken to calculate the percentage of children aged 7-19 years. In Sweden, 23.9 % of the population are aged under 20 years and 16.53 % were in the age range of the mandatory school system in 2004. In 2004, there were 1 489 437 school-aged children in Sweden. It can be noted that the proportion of the population up to 19 years (23.9 %) fits closely with the 24.2 % for the EU in 1998 (van den Hazel & Zuurbier 2005).

**Table 1:** Estimated DALYs per year per million of the population from children aged 7–19 in the EUR A epidemiological sub-region

| Age group and noise exposure level | Percentage of population exposed to given noise level | Percentage of population who will develop cognitive impairment | Number impaired per million | DALYs lost per million |
|---|---|---|---|---|
| 7–19 years, < 55 $L_{dn}$ | 11.24 | 0 | 0 | 0.0 |
| 7–19 years, 55–65 $L_{dn}$ | 3.14 | 20 | 6 281 | 37.7 |
| 7–19 years, 65–75 $L_{dn}$ | 1.82 | 50 | 9 090 | 54.5 |
| 7–19 years, > 75 $L_{dn}$ | .33 | 75 | 2 475 | 14.9 |
| All other age groups | 83.47 | 0 | 0 | 0.0 |
| Total | 100.00 | | 17 846 | 107.1 |

## RESULTS

*Percentage of noise exposed children*

There are no relevant figures for how many children are exposed to different noise levels. What are available are estimates of the percentage of people exposed to noise at different levels in the EU. Roovers et al. (2000) reported that stated that around 68 % of the population is exposed to $L_{dn}$ levels < 55, 19 % to 55–65, 11 % to 65–75 and 2 % to > 75. Although statistics for the specific countries within geographical regions such as the EU may vary the figures in Roovers et al. (2000) were extrapolated estimate how many percent of the children (expressed as percentages of the whole population) were exposed to noise.

*Likelihood of cognitive impairment when noise exposed*

As argued above, Figure 1 indicated that within the noise exposure bracket 55–65 $L_{dn,}$ there is approximately 20 % impairment. In the bracket 65–75 $L_{dn,}$ the number should be in the range of 45–50 % and above 75 $L_{dn}$ in the range of 70–85 %. Thus, in Table 1 the values of 20, 50 and 75 % were in inserted as an estimated of how many children will be cognitively impaired.

### Number of cases of and YLD from cognitive impairment caused by environmental noise

Combining the number of children exposed with the likelihood of cognitive impairment if exposed, the number of children with noise-induced cognitive impairment can be calculated. To estimate YLD due to the cognitive impairment, this number is multiplied by the DW of 0.006 (Table 1).

The number of DALYs per million children aged 7–19 in the EUR A is estimated to 107.1, The absolute DALY for the EUR A countries, with an estimated total population of 420,503 million, is therefore 45 036.

**Uncertainties, limitations and challenges**

*Source of noise*

The slopes reported in Figure 1 are mainly for aircraft noise. In contrast to the Munich study, which focused on aircraft noise, the RANCH study also included road traffic noise. But for road traffic noise, there was no indication of a significant impairment of children's cognition. As an explanation, the authors pointed out that aircraft noise, because of its intensity, the location of the source, and its variability and unpredictability, is likely to have a greater effect on children's reading than road traffic noise, which might be of a more constant intensity. Thus, it is conceivable that aircraft noise is more damaging than road traffic noise for children's cognition. This may also be true when the $L_{dn}$ level is controlled for, which has been reported for children's memory in an experimental acute noise study (Hygge 2003).

Even though there may be a degree of difference between aircraft and road traffic noise, acting on the safety principle would suggest treating them as equally damaging to children's cognition and to assume that there is approximately the same response effect regardless of noise source. This may, however, tend to overestimate the effects of road traffic noise.

*Design of epidemiological studies*

It should be noted that the RANCH study was a cross-sectional study in contrast to the prospective, longitudinal Munich study. This may make the Munich study more powerful in picking up unconfounded cause–effect relationships between noise exposure and outcomes.

*Possibility of long-term cognitive impairment from chronic noise exposure*

The DALYs calculated in Table 1 have not taken into account any lasting or long-standing impairment of cognitive functioning that could occur as a result of long-term noise exposure. Our calculations are restricted to the period in children's life when they attend primary school, assuming that the impacts of noise are negligible on the cognitive function of adults. This assumption is very conservative, however, because it is more likely that children who have passed through the mandatory school system in a noisy environment would live with a long-term consequence of cognitive impairment. They are also more likely to live in a noisy environment even after the schooling period, which is more likely for children who go to school in areas exposed to aircraft noise. It would be realistic to assume that the impaired cognitive function will carry over to the years after the schooling period. If future studies provide an estimation of the severity and the duration of such chronic effect of noise on cognitive function, the calculation of DALYs should be updated.

*Assumption of the duration of the impact*

There is some evidence from the Munich study (Hygge et al. 2002) that after the cessation of exposure to aircraft noise, children (age 9–11 years) recover within 18 months to the cognitive performance levels of their year-mates who were not exposed to much aircraft noise. Thus, it is possible that, at least for young children, chronic noise effects are reversible and that the DWs will diminish with increasing age. However, we assumed in our calculation that the effects are temporary and recovery is quicker, yielding YLD values that are conservative.

*Assumption of the exposure–risk relationship*

As pointed out above, with reference to the linear and sigmoidal accumulation of effects in Figure 3.2, we have most likely not overestimated the fractions of children affected in the noise exposure ranges 65–75 $L_{dn}$ (50 %) and > 75 $L_{dn}$ (75 %). Further, we might have underestimated the average DW (0.006) for those affected by the higher level of noise. These two conservative assumptions may have led to a significant underestimation of the real DALYs in the EUR A epidemiological sub-region in Table 1. For example, if DW doubles and quadruples to 0.012 and 0.0024 in the exposure brackets 65–75 $L_{dn}$ and > 75 $L_{dn}$, respectively, the DALYs will be much greater than shown in Table 1.

*Policy considerations*

An alternative to viewing the noise-induced cognitive impairment of children from a burden-of-disease perspective is to analyze the impairment in terms of wasted learning units. The learning units could be given a monetary value in wasted teaching hours in schools – wasted for the teachers, the pupils and society. Therefore, the societal impact will probably be larger than the impact reflected by DALYs, which solely estimate the impact on specific cognitive impairment. A calculation of wasted learning units instead of DALYs is probably a more complicated task, with many more uncertain parameters. For the time being, DALYs from noise-induced impairment of cognition in children, together with DALYs from other environmental risks, may provide evidence for prioritizing policy options, such as lowering recommended noise levels in control guidelines for schools and learning.

## CONCLUSIONS

Reliable evidence indicates the adverse effects of chronic noise exposure on children's cognition. There is no generally accepted criterion for quantification of the degree of cognitive impairment into a DW. However, it is possible to make a conservative estimate of loss in DALYs using the methods presented in this chapter. It is important to consider the assumptions, uncertainties and limitations in the methods when interpreting the estimated values of END.

**Note.** This paper is a summary of a chapter (Hygge 2011) in a recent WHO-publication on *Burden of Disease from environmental noise in Europe*.

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# The long-term effects of aircraft noise exposure on children's cognition: findings from the UK RANCH follow-up study

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## INTRODUCTION

Exposure to transport noise is an increasing and prominent feature of the urban environment. The RANCH project (Road Traffic Noise and Aircraft Noise Exposure and Children's Cognition and Health), the largest study of noise and children's cognition undertaken to date, examined the effects of aircraft noise and road traffic noise exposure at primary school on the cognitive performance of 2,844 9-10 year old children attending 89 schools around Heathrow (London), Schiphol (Amsterdam), and Barajas (Madrid) airports. The study found linear exposure-effect relationships between aircraft noise exposure at school and children's reading comprehension and recognition memory (Clark et al. 2006; Stansfeld et al. 2005).

Whilst previous studies had demonstrated effects of chronic aircraft noise exposure on primary school children's reading comprehension and long-term memory, comparing children with high noise exposure with those with low noise exposure (Haines et al. 2001a; Hygge et al. 2002), the RANCH study was the first to examine exposure-effect relations and to compare the effect of noise exposure on children's cognition across countries. The development of cognitive abilities such as reading are important not only in terms of educational achievement but also for subsequent life chances and adult health (Kuh & Ben-Shlomo 2004). To understand the causal pathways between noise exposure and cognition, and design preventive interventions, there is a need to study these associations longitudinally. However, few longitudinal studies have examined the effects of persistent exposure throughout the child's education: a study over only a one-year period found that deficits in reading comprehension persisted and that children did not adapt to their noise exposure (Haines et al. 2001b). Studies of noise abatement suggest that a reduction of noise exposure eliminates previously observed reading deficits (Bronzaft 1981; Hygge et al. 2002) but studies of the long-term consequences of noise exposure during primary school for later cognitive development have not been conducted.

This study followed the UK sample of the RANCH cohort to examine the long-term effects of aircraft noise exposure at primary school on children's reading comprehension. This paper examines whether children who attend aircraft noise exposed primary schools experience impaired reading comprehension during secondary school, compared with peers who were not exposed to aircraft noise at primary school. The paper also examines associations between aircraft noise exposure at secondary school and reading comprehension.

METHOD

## Design

A quantitative longitudinal epidemiological follow-up of the UK RANCH cohort, six years after the initial RANCH baseline study was carried out. This was an exposure-effect study with participants drawn from across a range of aircraft noise exposures at school from low to high at both baseline and follow-up.

## Pilot study

*Tracing the cohort:* the cohort was originally selected, on the basis of noise exposure at primary school, from the London Boroughs of Hounslow, Hillingdon, and Slough. We traced the cohort members using home address provided at baseline, through primary and secondary schools, and Local Education Authorities (LEAs). The secondary school attended for 77.8 % [N=1,054] of the sample was identified: no secondary school could be identified for 18.5 % [N=251] of the sample and a further 3.7 % [N=50] declined to take part in the follow-up study during the pilot study phase. Whilst the baseline study was conducted in 29 schools in 3 boroughs, the sample was traced to 80 secondary schools in 13 boroughs [excluding those schools outside of West London], with the majority remaining in Hounslow [31.2 %], Hillingdon [16.2 %], and Slough [18.6 %], or in the adjacent boroughs of Richmond [3.5 %], Surrey [3.0 %] and Windsor & Maidenhead [2.4 %]. It was not feasible to follow-up the sample in other boroughs where there were less than 12 cohort members per LEA or in boroughs outside West London [2.9 %]. Thus, 1015 cohort members from 58 secondary schools could participate in the follow-up study (74.9 % of the original sample).

*Pilot of test materials:* At baseline a range of cognitive abilities were measured, including reading comprehension, long-term memory, and working memory during a test session which lasted for one morning. At follow-up we had access to the participants for one 45-minute class and planned to measure reading comprehension, which had shown the strongest association with aircraft noise exposure at baseline. At baseline, reading comprehension was measured using the Suffolk Reading Scale 2, Level 2: a 30 minute test of 76 items suitable for 8-11 year olds (Hagley 2002): a test suitable for older children was required for the follow-up study. A pilot study of 89 14-15 year olds attending 3 secondary schools in Tower Hamlets conducted in early 2007 compared two reading comprehension tests: the Suffolk Reading Scale 2, Level 3 (Hagley 2002) and the Access Reading Test (McCarty & Crumpler 2006), and piloted a child questionnaire, adapted from the baseline child and parent questionnaires, assessing socio-demographic factors. Between and within group analyses of the reading comprehension tests revealed that participants were more likely to complete the Suffolk test compared with the Access test. Scale reliability was also higher for the Suffolk test (alpha=0.90 versus 0.83). The Suffolk test was selected for use in the follow-up given the stronger descriptive data from the pilot study, as well as the comparability afforded with the baseline measure of reading comprehension.

## Measures

*Noise Exposure Assessment:* At both baseline and follow-up aircraft noise estimates were based on 16-hour outdoor $L_{Aeq}$ contours available nationally from the Civil Aviation Authority. At baseline these data were from July to September 1999; at follow up these data were from July to September 2007. These contours were used to estimate aircraft noise exposure at school for each participant, based upon postcode data. At baseline acute noise measurements during testing were taken inside and outside the classroom: however, analyses revealed that acute noise had no effect on the observed association between aircraft noise and reading comprehension: acute noise was therefore not measured during the follow-up study. Aircraft noise exposure at baseline and follow-up are analysed as continuous variables.

*Reading Comprehension:* was measured using the Suffolk Reading Scale 2 Level 2 at baseline and Level 3 at follow-up (Hagley 2002). These are established, nationally standardised tests. The Level 2 test is a 30 minute test of 86 items suitable for 8-11 year olds; the Level 3 test is a 30 minute test of 76 items suitable for 11-15yrs 4m[1]. The test contains multi-choice questions with 5 potential answers. The questions become progressively harder as the child works through the test. The test, introduced as a ‘complete the sentence activity’, was conducted in silence, in exam-like conditions, and was timed out after 30 minutes. The test produces standardised scores using national norms and was converted to Z-scores for consistency with the baseline reading scale data.

*Potential Confounding Factors*: Data was available from child and parent questionnaires administered at baseline which assessed socioeconomic status, parental and child health, and other demographic factors. At baseline the schools were matched in terms of sociodemographic data, which was not possible at follow-up. Baseline confounding factors included in the analyses include the child’s age and gender, parental employment, crowding in the home, home ownership, mother’s educational attainment, parental support for school work, long-standing illness of the child, main language spoken at home, and classroom glazing (Stansfeld et al. 2005).

## Procedure

1,015 participants who had taken part in the initial baseline RANCH study in primary school, who now attended secondary schools in Hillingdon, Hounslow, Slough, Windsor & Maidenhead, Surrey, and Richmond, were invited to take part in the follow-up study. The participants were all in school year 11, aged 15-16 years. Data was collected from March to May 2008, during a 45 minute lesson. Written consent was obtained from the head teacher. Parents and participants received an information letter about the study one week prior to data collection; passive consent was obtained from parents who could opt their child out of the study if they wished. Written consent was obtained from the participant on the day of the study, after giving a further verbal explanation of the study and an opportunity to answer questions. Ethical approval for this study was obtained from the Queen Mary Research Ethics Committee.

## Statistical analysis

Initial analyses compared the characteristics of the cohort members who took part with those who did not take part in the follow-up to ascertain the representativeness

[1] At the time of the study, no standardised reading test in the UK was suitable for children 16 years or older. Our sample included children aged 15 and 16 years of age. We discussed this with the publishers of the Suffolk Reading Scale 2, NFER-NELSON, who foresaw no additional problems of using the test with a sample up to 16yrs 6m (Personal Communication).

of the achieved follow-up sample. Then the baseline model of aircraft noise exposure at primary school on reading comprehension was re-run on the follow up-sample, to see if it could be replicated in this sub-sample. Descriptive statistics exploring patterns of aircraft noise at primary and secondary school for the sample were examined. Multilevel modelling linear regression analyses examining the effect of primary school and secondary school aircraft noise exposure on follow-up reading comprehension were carried out. These models take into account the hierarchical nature of the data, of pupils being nested within schools and adjusted for confounding factors measured at baseline, which assessed socioeconomic status, child health, and other demographic factors.

## RESULTS

### Response rate and attrition

461 participants [45.4 %] of the target sample took part in the follow-up study: 201 males [43.6 %] and 260 females [56.4 %]. The age of the participants ranged from 15yrs 4m to 16yrs 8m, with an average age of 15yrs 7m.

Of those who did not take part in the study, it was not feasible to include 39 [3.8 %] participants who attended schools with fewer than 5 participants or 8 [0.8 %] participants who attended schools for children with special needs. The lack of consent for the study to take place in their school by head teachers resulted in 190 [18.7 %] participants not taking part in the study: very few parents or participants opted out of the study [N = 28, 2.8 %]. In total 11 out of the 58 schools refused consent for data to be collected in their school. 122 [12.0 %] participants had left the school in the year since the tracing work had been completed and could not be retraced: a further 167 [16.5 %] were unavailable for testing on the day due to absence from school or other school activities. This covered a broad range of reasons from other school activities, including GCSE exams, through to having been excluded from school.

In order to assess the impact of our response rate on the representativeness of the sample several analyses were carried out comparing the baseline characteristics of the cohort members who took part at follow-up [N-461] with those cohort members who did not take part at follow-up [N=554]. These analyses suggested no differential non-response by baseline exposure to noise or sociodemographic characteristics.

### Patterns of aircraft noise exposure at school at baseline and follow-up

Patterns of baseline and follow-up aircraft noise exposure are presented in Table 1 for the 461 cohort members who took part in the follow-up study. At baseline, aircraft noise range from 34 dBA to 68 dBA: the mean exposure was 54 dBA. At follow-up, aircraft noise exposure ranged from <50 dBA to 65.4 dBA: the mean exposure was 54 dBA. Overall, nearly half of the participants (N=217, 47 %) were attending secondary schools with a similar noise exposure level to their primary school: 51.4 % for <51 dBA, 60.5 % for 51-56.9 dBA and 64.4 % for 57-62.9 dBA. For those exposed to >63 dBA at baseline, most were attending secondary schools with exposure between 57-62.9 dBA (84.2 %): only 5 % remained in schools with the highest exposure (>63 dBA). The data indicate that in our sample, some cohort members remain exposed to high levels of aircraft noise at secondary school, whilst some have moved from noise exposed to quieter schools, and some have moved from quieter schools to noisier schools at follow-up.

**Table 1:** Noise exposure at primary and secondary schools in Hounslow, Hillingdon, Slough & Windsor, Surrey, Berkshire, and Richmond for the cohort who participated in the follow-up (N=461)

| Aircraft noise exposure at primary school ↓ | Aircraft noise exposure at secondary school ↓ | | | |
|---|---|---|---|---|
| | <51 dBA N [%] | 51-56.9 dBA N [%] | 57-62.9 dBA N [%] | >63 dBA N [%] |
| <51 dBA | 75 [51.4 %] | 38 [26.0 %] | 33 [22.6 %] | 0 [0.0 %] |
| 51-56.9 dBA | 20 [16.8 %] | 72 [60.5 %] | 27 [22.7 %] | 0 [0.0 %] |
| 57-62.9 dBA | 8 [7.9 %] | 27 [26.7 %] | 65 [64.4 %] | 1 [1.0 %] |
| >63 dBA | 4 [4.2 %] | 6 [6.3 %] | 80 [84.2 %] | 5 [5.3 %] |
| [%]=row %. | | | | |

## Effects of aircraft noise at school on reading comprehension

Initially, the baseline model of aircraft noise exposure at primary school on reading comprehension was re-run on the follow-up sub-sample (N = 461) to assess whether the original RANCH reading findings (Clark *e*t al. 2006; Stansfeld et al*.* 2005) could be replicated in the sub-sample participating at follow-up. Multilevel modelling analyses (Table 2) indicated that the effect size for the UK sample in the original sample was replicated in our sub-sample. This is suggestive that the achieved sample is representative of the UK baseline cohort.

Of the sample, 20 % had reported both parents as being unemployed at baseline; 40 % did not own their home; 22 % had reported a crowded home; 27 % of the sample had a long-standing illness; and 20 % had reported not speaking English at home; 57 % of the follow-up sample was female. Table 3 (model 1) shows the multilevel model analyses for the effect of aircraft noise at primary school on secondary school reading comprehension, adjusted for baseline socioeconomic and demographic factors. The model shows that for every 1 dB increase in primary school noise exposure, performance on the reading comprehension test decreases by -0.007: however, this effect was not significant, indicating that children who attended noise exposed primary schools did not have significantly poorer reading comprehension compared with children who attended non-noise exposed primary schools.

**Table 2:** The effect size of aircraft noise at primary school on reading comprehension at primary school for each county and for the UK sub-sample who took part in the follow-up study

| | B† | SE | Confidence interval (95 %) | p-value from $\chi^2$ |
|---|---|---|---|---|
| Original findings at baseline | | | | |
| Pooled estimate | -0.008 | 0.003 | -0.014 to -0.002 | 0.009 |
| UK | -0.009 | 0.005 | -0.019 to 0.001 | |
| NL | -0.006 | 0.007 | -0.020 to 0.008 | |
| Spain | -0.006 | 0.005 | -0.016 to 0.004 | |
| Original finding at baseline for the follow-up sample | | | | |
| UK | -0.009 | 0.005 | -0.019 to 0.001 | 0.051 |
| † indicates change in reading z-score per 1 dB increase in noise exposure at primary school | | | | |

Table 3 (model 2) shows the multilevel model analyses for the effect of aircraft noise at secondary school on secondary school reading comprehension, adjusted for baseline socioeconomic and demographic factors. The models show that for every 1 dB increase in secondary school noise exposure, performance on the reading comprehension test decreases by -0.023: however, this effect was not significant, indicating that children who attended noise exposed secondary schools did not have poorer reading comprehension compared with children who attended non-noise exposed secondary schools.

**Table 3:** The multilevel model parameter estimates for aircraft noise at primary school and secondary school on reading comprehension at secondary school for the UK follow-up sample (N=342)

| | Model 1 Aircraft noise at primary school | | | Model 2 Aircraft noise at secondary school | | |
|---|---|---|---|---|---|---|
| *Fixed coefficients* | B | 95 % CI | p-value | B | 95 % CI | p-value |
| | | | | | | |
| Aircraft noise at primary school | -0.007 | -0.02 to 0.004 | 0.22 | - | - | - |
| Aircraft noise at secondary school | - | - | - | -0.023 | -0.060 to 0.012 | 0.200 |
| Age | -0.00002 | -0.0003 to 0.0002 | 0.87 | 0.0000001 | -0.0002 to 0.00027 | 0.952 |
| Female | -0.30 | -0.51 to -0.90 | 0.005 | -0.31 | 0.52 to -0.10 | 0.003 |
| Employed | -0.05 | -0.34 to 0.24 | 0.73 | -0.08 | -0.36 to 0.20 | 0.578 |
| Crowded | -0.23 | -0.49 to 0.03 | 0.08 | -0.24 | -0.50 to 0.01 | 0.063 |
| Home owner | 0.32 | 0.085 to 0.55 | 0.007 | 0.27 | 0.05 to 0.50 | 0.018 |
| Mother's education | -0.60 | -0.98 to -0.23 | 0.002 | -0.58 | -0.94 to -0.21 | 0.002 |
| Long standing illness | -0.02 | -0.25 to 0.21 | 0.85 | 0.01 | -0.21 to 0.23 | 0.923 |
| Speak main language at home | 0.11 | -0.16 to 0.39 | 0.42 | 0.16 | -0.12 to 0.45 | 0.276 |
| Parental support | 0.08 | 0.03 to 0.14 | 0.001 | 0.78 | 0.03 to 0.13 | 0.003 |
| Classroom glazing | 0.26 | -0.97 to 0.15 | 0.68 | - | - | - |
| Road noise at primary school | 0.007 | -0.008 to 0.022 | 0.395 | - | - | - |
| | | | | | | |
| *Random parameters* | B | SE | | B | SE | |
| Level 2: Primary school | 0.90 | 0.07 | | 0.81 | 0.06 | |
| Level 1: Pupil | 0.014 | 0.03 | | 0.10 | 0.05 | |
| B = change in outcome score associated with 1 db change in noise | | | | | | |

## CONCLUSION

This is the first study to examine the long-term effects of aircraft noise exposure at primary school on children's later cognitive performance. This study compared the performance on a standardised reading comprehension task for children aged 15-16 years of age, who attended primary and secondary schools exposed to varying levels of aircraft noise around London Heathrow airport. This study found that children who attended aircraft noise exposed primary schools did not have significantly poorer reading comprehension at secondary school compared with children who were not exposed to aircraft noise at primary school. Similarly, children who attended aircraft noise exposed secondary schools did not have significantly poorer reading comprehension compared with children who were not exposed to aircraft noise at secondary school.

These conclusions however, need to be considered in the light of some of the limitations of this study. The achieved sample size for the follow-up of the RANCH study was fairly small with 342 participants having complete data from baseline and follow-up. The sample size could potentially have influenced the findings in several ways. Firstly, the coefficients for the effect of aircraft noise at primary and secondary school are both negative and sizeable, but are not significant. This suggests that whilst aircraft noise was associated with impaired performance on the reading comprehension test the achieved sample may lack the power to detect a statistically significant difference. This argument is further supported by the similarity in the coefficient for primary school noise exposure and its effect on reading comprehension in secondary school (-0.007) with the earlier finding of an effect on reading comprehension in primary school (-0.009) (Stansfeld et al. 2005). Secondly, many previous small-scale studies of noise effects on children's cognition have failed to demonstrate effects, whilst larger studies, such as the RANCH study, have demonstrated effects. This suggests that smaller scale samples in this field are more likely to result in type II errors, which may be the case in our follow-up study. Future studies need to ensure a larger sample is followed over-time, in order to test whether effects of noise exposure in primary school, on secondary school cognitive performance can be demonstrated.

One considerable limitation for longitudinal studies is attrition and we have lost over half of the original UK RANCH sample from our follow-up sample as we were not able to trace them from primary school into secondary school; because schools refused to take part in the follow-up; and because pupils were often absent from school or involved in other school activities on the day of data collection. We have compared whether the follow-up sample is representative of the UK baseline cohort in two ways. Analyses comparing the baseline characteristics of cohort members who took part in the follow-up with those who did not revealed no differential non-response by baseline noise exposure at primary school or by sociodemographic characteristics. Further, we were able to replicate the original RANCH findings of an association between aircraft noise at primary school and reading comprehension in the sub-sample who took part in the follow-up. Together, these analyses suggest that the achieved sample is largely representative of the UK baseline cohort, however, given the level of attrition in the sample, we should consider the results as indicative rather than definitive. Also, in terms of the secondary schools sampled, it should be remembered that the secondary schools may not be representative of the population or of aircraft noise exposure, as the sample was not selected by secondary school noise exposure, per se.

Further limitations of the study include a lack of information about exposure to road traffic noise and air pollution at secondary school, about aircraft noise exposure at the child's home at follow-up, and about internal acoustic conditions in the classroom and acute noise exposure during testing. The study is also restricted to one cohort in only one country, so the results may be country and cohort specific. However, to our knowledge, this is the first study to prospectively examine the effect of aircraft noise exposure in primary school and its effect on cognitive performance in secondary school and there are few large scale studies of noise effects on children's cognition which could be followed-up in this way. Other strengths of this study include data on a comprehensive and wide-range of individual-level confounding factors as well as the use of multilevel modelling which enabled the effect of both school-level and individual-level variables to be examined.

Overall, the findings of the current study are mixed; whilst there was no significant effect of aircraft noise exposure at primary school or secondary school on reading comprehension assessed at secondary school, the results do indicate a trend for noise exposure on both occasions to be associated with poorer performance on reading comprehension. These findings, taken with the evidence from the RANCH study for an effect of aircraft noise at primary school on reading comprehension assessed at primary school, raise concerns regarding the effect of chronic aircraft noise exposure at school on children's reading ability. Further, the coefficient for aircraft noise exposure at secondary school was three times larger than the coefficient observed for aircraft noise exposure at primary school. This could reflect a larger influence of contemporaneous secondary school aircraft noise exposure compared with exposure at primary school, but it could be indicative of a larger, cumulative effect of noise exposure at school on the child's cognition, observable by the end of the child's school career. Such an effect would be supported by previous evidence: a study over only a one-year period found that deficits in reading comprehension persisted and that children did not adapt to their noise exposure (Haines et al. 2001b). To understand the causal pathways between noise exposure and cognition, and to design preventive interventions, there is a need for further longitudinal evidence of the effects of noise exposure throughout the child's education.

Further analyses of the RANCH follow-up study data will examine whether some children are more susceptible to long-term effects of noise on reading comprehension. The association of noise exposure at primary and secondary school on educational achievement, as measured by national exam data for the participants, will also be examined and may yield less equivocal findings. As well as the need for further longitudinal studies examining the long-term consequences of noise exposure during primary school for later cognitive development, future research should also examine the interaction between external noise exposure and internal classroom acoustics; assess the potential protective effect of classroom insulation to reduce noise effects on cognition; and further assess exposure-effect relationships between primary and secondary school noise exposure and cognition.

The results of this project have implications for noise policy within the UK and the results have relevance to European, national and local authorities involved in public health, transport planning, and land-use planning. This study is the first to utilise prospective data to assess the long-term consequences of noise exposure during primary school for later cognitive development but the findings are limited by the scale of the follow-up study. In terms of policy implications, taken as a whole, the RANCH study findings indicate that a chronic environmental stressor – aircraft noise exposure at school – could impair cognitive development in children, specifically reading comprehension. Schools exposed to high levels of aircraft noise are not health educational environments.

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# Effects of noise, job characteristics and stress on mental health and accidents, injuries and cognitive failures at work

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## INTRODUCTION

This paper addresses two key topics in noise research. The first is whether effects of noise are specific or reflect other correlated attributes. In the workplace noise exposure is often associated with other negative factors such as exposure to dangerous machinery or having to perform demanding tasks. If one finds associations between noise levels and outcomes such as accidents and injuries one needs to ask whether it is the noise per se that leads to such effects or whether other job characteristics associated with noise exposure underlying the association with accidents and injuries.

The second issue examined here is the explanation of non-auditory effects of noise. It has often been the case that noise effects have been explained in terms of an increase in stress (Babisch 2000). However, recent studies suggest that environmental noise exposure does not lead to reliable effects on key outcomes of the stress process (stress hormones – Maass & Basner 2006; immune parameters – Prasher 2010; and mental health – van Kamp et al. 2007). Research has not addressed the issue of whether occupational noise exposure influences both perceived stress and mental health outcomes. If noise exposure influences these measures then one needs to examine whether such effects reflect associations with other psychosocial stressors or are independent effects of noise. This was investigated here and the present study also examined effects of noise on cognitive failures, injuries and accidents at work. This was done by conducting secondary analyses of a large community sample. The aim was to determine whether noise influences the stress process (independently of other occupational factors) and whether effects of noise on accidents, injuries and cognitive failures were due to noise or correlated attributes. The next section reviews research on noise and safety at work.

Smith (1990) reviewed studies of the effects of noise on accidents. Cross-sectional studies have produced conflicting results, with some showing a greater accident rate in high noise areas (e.g. Kerr 1950; Cohen 1974) but others (e.g. Lees 1980) reporting no effect of noise. All of these early studies suffer from the problem that noise exposure was confounded with other uncontrolled factors. Intervention studies (e.g. Cohen 1976) suggest that reduction of noise exposure does lead to lower accident rates. However, these results can be interpreted in other ways (e.g. changes in morale) and a reduction in injuries was seen in both workers who used hearing protectors regularly and those who did not. Another major problem in this area is the definition of an accident. In some studies it is likely that an accident refers to an injuring requiring medical attention whereas in others the injuries are likely to have been more minor. There is a need, therefore, to examine associations between noise exposure and both accidents and minor injuries. Many everyday errors (failures of attention, memory or action) do not lead to accidents. However, in certain contexts human error is a major cause of accidents and it is important to determine where noise exposure influences the occurrence of cognitive failures. Smith and

Stansfeld (1986) compared self-reports of everyday errors given by people who lived in a high aircraft noise area with those given by people in a quieter area The results showed that the high noise group reported a greater frequency of everyday errors. It is now important to determine whether such associations are also observed in the workplace, and whether they reflect noise or other correlated job characteristics.

Smith (2003) found that perceptions of noise exposure were related to reports of accidents. minor injuries and cognitive failures. Clear dose-response effects were observed and this suggests that some causal relationship were present. Analyses were carried out to determine whether the associations between noise exposure and the outcomes reflected noise or other correlated job characteristics. The results suggested that the association between noise and accidents largely reflected other correlated job characteristics. In contrast to this, controlling for other factors and excluding those exposed to other physical agents did not remove the effects of noise exposure on minor injuries or cognitive failures. The effect of noise on minor injuries was greater at higher perceived intensities. However. the effect on cognitive failures was more apparent in those who perceived that background noise disturbed their concentration. As this last measure of noise exposure implies a functional deficit it is not too surprising that it should be associated with another measure of cognitive problems. The question measured not only exposure to noise but also sensitivity to its effects which may make it more useful than general questions about exposure. The present paper extends the above research by including a greater number of psychosocial characteristics in the analyses. Smith, McNamara and Wellens (2003) found that the physical working environment (of which noise exposure formed a part) was significantly associated with safety at work even when psychosocial factors were covaried. In contrast, the physical working environment was no longer associated with stress and mental health when psychosocial factors (job demands, control, support and effort-reward imbalance) were included in the analyses. The present investigation re-examined this issue with the focus being on perceptions of noise exposure and a model of stress outlined below.

Many models of stress (see Mark & Smith 2008) share the following features. First, they consider job characteristics that are perceived as negative (e.g. demands – Karasek 1979; high extrinsic effort – Siegrist 1996) or as positive (e.g. social support, control or reward). Perceived stress is seen as an imbalance between demands and control/support (Karasek 1979) or effort-reward imbalance (Siegrist 1996). Negative mental health changes (increases in anxiety and depression) then often result. In order to assess whether noise influences the stress process on needs to look at associations between noise and stress and mental health. One then needs to determine whether these effects reflect other psychosocial stressors or whether there are independent effects of noise on stress which could underlie many of the non-auditory effects of noise on health.

## METHOD

The present paper reports a secondary analysis of a database formed by combining the Bristol Stress and Health at Work study and the Cardiff Health and Safety at Work study. Details of the database are given in Smith et al. (2003) and Smith (2000, 2001). This database contained information on perceptions of noise exposure at work, job characteristics, accidents, injuries and cognitive failures, and stress, anxiety and depression. In addition, it contained information about possible confounders that need to be controlled in such analyses (e.g. demographics and health-related behavior).

### Ethical approval

The Bristol Stress and Health at Work study was carried out with the approval of the local regional ethical committee. The Cardiff Health and Safety at Work was approved by the Cardiff University School of Psychology Ethics Committee. It was also scrutinized by the Local Research Ethics Committee, which deemed that formal ethical approval was not necessary.

### Measurement of perceptions of noise exposure at work

Perceived noise exposure was measured by two questions. One asked how frequently they were exposed to noise which led to a ringing in the ears. The second asked about exposure to noise that disturbed concentration. A 4-point scale (from 'Never' to 'Often') was used to respond to the questions.

### Measurement of accidents, injuries and cognitive failures at work

Frequency of accidents that required medical attention was recorded (number in last 12 months) and the frequency of minor injuries (not requiring medical attention from another person e.g. cuts and bruises) and cognitive failures were rated using a 5-point scale ('not at all' to 'very frequently').

### Measurement of stress, anxiety and depression

Stress at work was measured using a 5-point scale from 'Not at all' to 'Extremely stressed' (Smith 2001). Anxiety and depression were measured using the Hospital Anxiety and Depression Scale (Zigmond & Snaith 1983).

### Psychosocial stressors

The 21-item version of the Effort-Reward Imbalance Questionnaire (ERI, Siegrist 1996) was as used in the Whitehall II Study (Kuper et al. 2002). Three subscales measured intrinsic effort (internal motivations e.g. "overcommitment" to work) extrinsic effort (external pressures) and internal reward (adequate rewards). Participants respond on a four-point likert scale indicating to what extent (if experienced) they find the suggested work situations distressing. A 27-item version of the Job Content Questionnaire (JCQ: Karasek et al. 1998) was used. Four subscales measured job demands (workload, time pressure); decision authority (control over decisions); skill discretion (opportunity to use skills); and levels of social support. Participants responded as to how often they experienced the suggested situations at work on a four point likert-scale.

### Control variables

The following variables were also included in the regressions to control for other factors: age, gender, income, educational level, social class based on occupation, full/part-time employment, negative affectivity and working hours.

## Sample

Details of the sample are given in Smith (2003). In summary there were 6,512 workers (43.4 % male), with 71 % living in the Cardiff area and 29 % in the Bristol area. About a quarter of the sample had manual jobs.

In the following analyses noise exposure was recoded as (1) High noise exposure: those who were never exposed to deafening noise versus those who were; (2) Distracting noise: those who were never exposed to deafening noise versus those who were. In further analyses those who were exposed to noise that led to ringing in the ears were excluded from analyses of distracting noise.

RESULTS

## Effects of noise on accidents

Table 1 shows that exposure to noise that led to ringing in the ears was associated with more accidents ($p<0.0001$), more frequent injuries ($p<0.0001$) and more cognitive failures ($p<0.0001$). These effects were also significant for exposure to distracting noise (Table 2). These effects remained significant when psychosocial stressors were covaried.

**Table 1:** High intensity noise, accidents, injuries and cognitive failures.

| | Low noise | High noise |
|---|---|---|
| % having accident | 7.4 % | 16.5 % |
| % frequent injuries | 9.1 % | 26.2 % |
| % frequent cognitive failures | 11.2 % | 17.3 % |

**Table 2:** Distracting noise, accidents, injuries and cognitive failures.

| | Low Distraction | High Distraction |
|---|---|---|
| % having accident | 7.1 % | 8.3 % |
| % frequent injuries | 7.8 % | 13.8 % |
| % frequent cognitive failures | 10.0 % | 16.0 % |

## Effects of noise on stress and mental health

Table 3 shows that exposure to noise that led to ringing in the ears was associated with greater stress ($p<0.0001$), anxiety ($p<0.0001$) and depression ($p<0.0001$). These effects were also significant for exposure to distracting noise (Table 2 – all p-values $<0.0001$). These effects were no longer significant when psychosocial stressors were covaried. Perceived stress was most strongly influenced by job demands and extrinsic effort. Mental health was most strongly influenced by intrinsic effort.

**Table 3:** High intensity noise, stress and mental health problems.

| | Low noise | High noise |
|---|---|---|
| % at least moderate stress | 18.8 % | 25.0 % |
| % high anxiety | 29.2 % | 41.1 % |
| % high depression | 8.5 % | 15.4 % |

**Table 4:** Distracting noise, stress and mental health problems.

| | Low Distraction | High Distraction |
|---|---|---|
| % at least moderate stress | 16.2 % | 28.6 % |
| % high anxiety | 27.0 % | 38.3 % |
| % high depression | 7.5 % | 13.0 % |

## DISCUSSION

The present results confirm that occupational noise exposure is associated with an increased risk of accidents and injuries. This effect is observed with both intense noise and lower intensity noise that causes distraction. For both noise exposures there was an association with an increased frequency of cognitive failures. It is plausible to suggest that this effect of noise on human error underlies that seen for accidents and injuries. One must now consider the underlying mechanism for this effect. The effect was still significant when psychosocial stressors were covaried. Furthermore, associations between noise exposure and stress, anxiety and depression were no longer significant when Karasek (1979) and Siegrist (1996) dimensions were included in the analyses. This suggests that noise plays little part in stress and mental health problems of workers and that it may be unwise to interpret effects, such as the effects of accidents, injuries and cognitive failures, in terms of a stress mechanism.

One must now ask what other mechanisms could underlie the effects of noise found here. One type of effect that has been put forward to account for effects of noise on attention is “over-arousal” (Broadbent 1971). Attention is best at moderate levels of arousal because the person can select relevant cues from irrelevant ones. As arousal increases the person becomes too selective and misses relevant information as well. An alternative view is that accidents reflect the masking of information or interference with internal speech (Poulton 1977). This “auditory” effect of noise may be important in explaining other health effects of noise (see below).

One could argue that an explanation based on over-arousal is very similar to one based on noise increasing stress. Stress is now usually defined in terms of “Demands exceeding the ability to cope” and noise could add to this by creating and additional burden that has to be dealt with. This type of effect is important in terms of explanations based on noise using up processing resources. However, the present results show that the effects of noise are clearly different from those of psychosocial stressors such as job demands or effort-reward imbalance.

Smith (2010) has argued that we need more research on noise and health. Part of his argument is that we need better models of underlying mechanisms. It is likely that noise influences health and cognitive function through many different mechanisms (see the above account of accidents). These are likely to be a combination of auditory effects and subsequent non-auditory consequences. For example, chronic effects of noise have been demonstrated in children tested in quiet (Stansfeld et al. 2005) and these may actually reflect interference with speech perception (Hartley et al. 2000) which may lead to reduced cognitive functioning (Deary 1995). The outcome of long term exposure to noise may be a reduction in intelligence. Recent research (Gottfredson & Deary 2004) has shown that reduced intelligence is one of the biggest risk factors for long term health problems and mortality. The mechanism underlying this could be an increase in bio-markers that reflect the metabolic syndrome (Batty et al. 2008). This theory now needs to be tested by first demonstrating that noise impairs auditory perception and that this underlies the poorer reading comprehension found in children in noisy schools. Long-term follow up of those living in a noisy environment also needs to be done in order to examine whether these people are at greater risk of developing the metabolic syndrome.

The present paper has presented evidence suggesting that past and current approaches to the effects of noise on health and safety need to be modified in order to provide a greater understanding of the area that will be of relevance to policy and practice. It is also important to use new methods to address the old question of what are the effects of noise on health. For example, it is important to examine the effects of noise on gene expression as this may give a strong indication of future health effects. Similarly, noise and cognitive functioning can now be studied using a variety of brain imaging methods that can provide plausible mechanisms for observed behavioral effects. These new approaches must be combined with different methods of measuring noise exposure. Individual differences in noise sensitivity need to be refined to separate general biases in perception and response from those which are specific to noise. Noise exposure is usually combined with exposure to other risk factors (e.g. traffic noise is combined with air pollution). Future research must not only control for other factors but investigate the combined effects of noise and other agents.

In summary, previous research on the effects of noise on health has often been interpreted in terms of a stress model. Reviews of recent studies suggest that environmental noise exposure does not lead to reliable effects on key outcomes of the stress process (stress hormones, immune parameters and mental health). The present study examined whether occupational noise exposure influenced the stress process (measured by perceived stress and mental health) and whether this reflected noise per se or the psychosocial environment. The results showed that the effects of noise on stress and mental health were due to correlated attributes (job demands, effort-reward imbalance). In contrast, both intense noise and distracting noise were associated with more frequent accidents, injuries and cognitive failures, an effect that remained even when psychosocial factors are covaried. Possible mechanisms underlying these effects are discussed and it is argued that future research must elucidate the underlying mechanisms of established effects and use new methodologies to address non-auditory effects of noise.

## ACKNOWLEDGMENTS

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# Disruption of cognitive performance by sound: differentiating two forms of auditory distraction

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## INTRODUCTION

Attentional selectivity—the capacity to focus on task-relevant events and ignore effectively task-irrelevant events—is a core feature of all efficient information processing. In order to be maximally efficient, attention must be flexible so that it can be responsive to unexpected and potentially significant events outside the focus of attention. Flexibility is achieved by having a degree of processing of events that are at any one time outside the attentional focus. This is only achieved at some cost, however, both from the need to monitor events but also because such events have the potential to wrest attention away from task-relevant processing even when they are not in fact of interest or importance. Attentional control—which is essentially about mapping of events in the world onto one of a range of possible actions—cannot be completely efficient. Indeed, in the auditory modality there is evidence that all auditory information is processed in an obligatory fashion, making behavior particularly liable to distraction by sound.

A range of findings reviewed here suggest that this obligatory processing of sound can lead to two distinct forms of auditory distraction. The first—*competition-for-action*—occurs when the results of obligatory sound processing are similar to those of the focal task. The second—*interruption-of-action*—takes place when an unexpected sound draws attention away from the focal activity. In this paper, we focus on reviewing four lines of recent evidence that suggest that the two forms of distraction are distinct, namely: i) that the two forms act additively; as well as differences in the expression of each according to ii) the type of focal task; iii) the attentional load involved in stimulus-encoding; and iv) whether the focal information is being taken in or whether it is being acted-upon. We first provide an overview of each form of distraction.

## COMPETITION-FOR-ACTION

A great deal of the laboratory research on auditory distraction over the last 30 years or so has focused on the particular vulnerability of how we remember sequences. This is a basic and ubiquitous mental function that underpins language and thought. The typical paradigm involves presenting a list of usually visually-presented items (e.g. digits, words, or letters), slowly, one-by-one on a screen and requiring that they be remembered in the order in which they were presented. Sometimes, sound is presented that is irrelevant to the task and which the person is told to ignore. Despite its irrelevance, the sound disrupts serial recall appreciably compared to a quiet control condition (up to 30-50 % disruption for sound such as narrative speech; e.g. Colle & Welsh 1976; Salamé & Baddeley 1982; Jones et al. 1990; for further discussion of the psychometric characteristics of the effect, see Ellermeier & Zimmer 1997).

Many of the key empirical characteristics of the disruption of serial recall by irrelevant sound are well established and have been reviewed in greater detail elsewhere (e.g. Hughes & Jones 2001). In brief, the meaning of the sound plays little or no role in the disruption of serial recall nor does its intensity (at least within the range 48 to 72 dBA). Although speech was typically used in early studies (e.g. Colle & Welsh 1976), the effect is not specific to speech (Jones & Macken 1993). Rather, the chief characteristic underpinning the disruption is the presence of acoustic variation or 'changing state' (e.g. in timbre or pitch) within the sound. Thus, not only do changing-state speech tokens impair performance (e.g. "c, j, t, u, f, q…" compared to "c, c, c, c, c…"), changing-state tones (e.g. tones changing in frequency compared to the same tone repeated; Divin et al. 2001; Jones & Macken 1993) and changing band-pass noise bursts produce the impairment also. We have argued that the disruption is best explained by a conflict of two similar processes involving the maintenance of the order of events, or 'competition-for-action': Obligatory perception of changes in a changing-state sequence yields information about order (which would be impoverished or absent with a repeated item) which compete for, and hence compromise, the deliberate serial motor (vocal-articulatory) planning involved in supporting the reproduction of the order of the to-be-remembered items (e.g. Hughes et al. 2005; Jones & Macken 1993).

## INTERRUPTION-OF-ACTION

There is a distinct tradition of work on auditory distraction embedded originally within psychophysiological studies of the orienting response (OR; Sokolov 1963). The OR refers to the panoply of responses to a novel stimulus: physiological (e.g. increased skin conductance, heart-rate deceleration), motor (e.g. head and eye movements), and—most importantly in the present context—psychological (an involuntary shift of attentional focus). Importantly, the OR is assumed to habituate with repeated presentation of the initially-novel stimulus, as a memory for, or 'neuronal model' of the physical features of the repetitive stimulus is gradually established (e.g. Sokolov 1963). Attentional orienting to auditory stimuli has been demonstrated mainly using the oddball (or 'deviant') paradigm in which, following a repeated sound (e.g. tone 'A': AAAA…), an unexpected deviant sound is presented (e.g. a tone of a different frequency, B, i.e., AAAAB). The deviant produces disruption of an ongoing cognitive task, again even if that task is presented visually (e.g. Escera et al. 1998): ongoing action is interrupted momentarily to allow further evaluation of the novel, and hence potentially important, change within the auditory scene.

Whether this interruption-of-action mechanism can also explain the changing-state effect in serial recall (what we will term the 'unitary account')—making the competition-for-action account redundant—is moot. Rather than being due to a competition between two streams of order cues as we have argued, the changing state effect may just be a succession of ORs (e.g. Chein & Fiez 2010; Cowan 1995; Elliott 2002): When each stimulus differs from its predecessor ("c, j, t, u, f, q…"), the lack of a neuronal model of each stimulus means that each stimulus captures attention thereby causing a constant interruption of the focal serial recall task. In contrast, with a steady-state sound ("c, c, c, c, …"), each successive stimulus would be increasingly less likely to capture attention due to the development of a neuronal model of the stimulus (i.e., the capture mechanism habituates), leaving serial recall relatively unscathed. However, we now review a number of recently-emerging lines of evidence showing that this unitary model is not adequate, suggesting that there are therefore two distinct types of auditory distraction.

COMPETITION-FOR VS. INTERRUPTION-OF-ACTION

Recent work has used serial recall as a focal task to explore both types of auditory distraction effect, one involving sequences of stimuli, the other, the impact of single stimuli deviating from some background context. This work has yielded numerous lines of evidence which, when combined, indicate a double dissociation between the effects of deviant compared to changing-state sounds.

**i) Additive effects of changing-state and deviant sounds**

The view that changing-state stimuli (e.g. “c, j, t, u, k, q…”) disrupt serial recall because each stimulus captures attention (like a succession of deviants) predicts that introducing an additional deviant event into that sequence should have relatively little disruptive impact compared to when that same deviant event occurs within a steady-state, and hence habituated-to, sequence (“k, k, k, k, k…”). For example, a single deviation in the voice conveying an irrelevant steady-state sequence of speech tokens should be very likely to capture attention (“k, k, k, k, **k** k, k…”; where the ‘k’s are presented in a male voice, and the **‘k’** in a female voice). However, if that same item already captures attention because it is different in identity from its predecessors (“c, j, t, u, **k**, q…”)—the key assumption of the unitary account—then the fact that it differs also in voice should have relatively little impact.

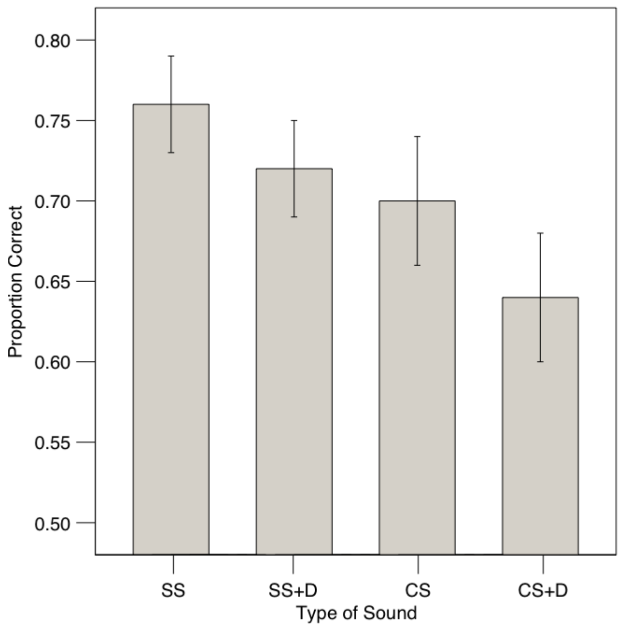


**Figure 1:** Proportion of items correctly recalled in a serial recall task in irrelevant sound conditions of steady-state (SS), steady-state plus a voice deviant (SS+D), changing-state (CS), and changing-state plus a voice deviant (CS+D). Adapted from Hughes et al. (2007)

However, the data indicate otherwise: As shown in Figure 1, the effect of a voice deviant is of the same magnitude whether it occurs in the context of a steady-state or changing-state sequence. In other words, the two effects are additive (Hughes et al.

2005, 2007) which suggests that changing-state stimuli are not already capturing attention from the focal task.

### ii) Focal processing modulates the changing-state effect but not the deviation effect

A defining principle of the competition-for-action account of the changing-state effect is that the effect should only be found when the focal task involves serial rehearsal, more specifically, when both the focal task and the sound share a common process, that of encoding order. Without a serial ordering component within the focal task, there would be no competition from the order cues derived from the changing-state sound and hence no disruption. This can be established by comparing two tasks identical in their perceptual characteristics, but where one task requires the maintenance of order. One variant of this approach involves presenting all but one of a well-known set of items (e.g. eight of the nine digits in the set 1-9) in a random order and the participant is required to report the missing digit (e.g. Buschke 1963). This task involves remembering all the items so that the missing items can be identified; however, the order of the items is immaterial to the task (Buschke 1963). The second variant uses the same lists, but this time one item from the list is re-presented (a 'probe') and the person is asked to report the item that followed it in the list. This task does indeed necessitate the retention of item order, just like serial recall. As predicted by the competition-for-action view, only the probe task is disrupted by changing-state irrelevant sound (Beaman & Jones 1997).

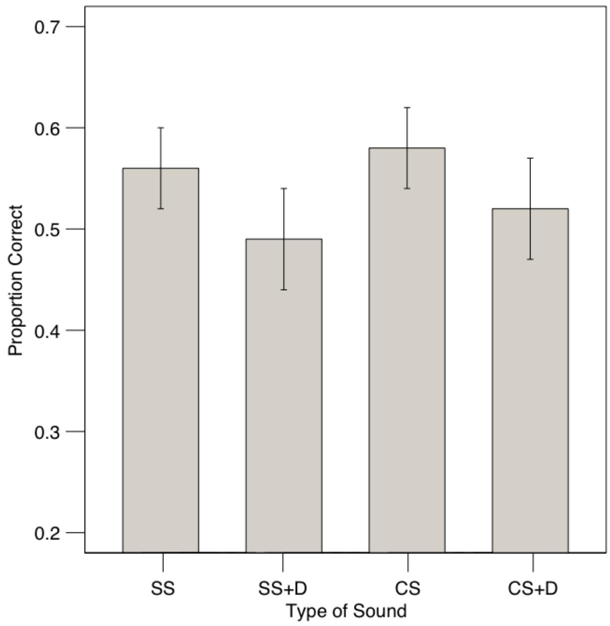


**Figure 2:** Proportion of items correctly recalled in a missing-item task in irrelevant sound conditions of steady-state (SS), steady-state plus a voice deviant (SS+D), changing-state (CS), and changing-state plus a voice deviant (CS+D). Adapted from Hughes et al. (2007)

Does the deviation effect depend on order retention? Figure 2 shows the results of a study in which we examined the impact of a deviant embedded in steady and changing-state sequences on missing-item performance (Hughes et al. 2007). As expected, there was no changing state effect on this task (e.g. Beaman & Jones 1997), but a clear deviation effect was evident (again regardless of the auditory background on which it took place). Indeed, deviation effects have been found in a range of other non-order based tasks including speeded classification of visually-presented digits (e.g. Escera et al. 1998). This would seem to make functional sense: The interruption of ongoing action due to a potentially important change in the auditory scene should not depend on the particular task a person is undertaking.

### iii) Attentional load involved in stimulus-encoding modulates the deviation effect but not the changing-state effect

If the deviation effect, but not the changing-state effect, is due to attention being captured away from the prevailing task, then making the focal task more attentionally-demanding should modulate the former effect more than the latter. One way of making the task more attentionally-demanding is to degrade the to-be-remembered items by embedding them in static visual noise (see Figure 3). A pilot study used a task in which a series of stimuli was presented one by one on a screen and each stimulus could be either a digit or a letter. Participants were simply required to press one of two buttons to indicate its category membership (digit or letter). Static noise slowed the person's speed of making the decision thereby validating the load manipulation. When the degraded digits were then used as to-be-remembered items in a serial recall task (high attentional load), the impact of a voice deviation was abolished. In contrast, the disruption caused by changing- compared to steady-state stimuli was not affected by increased load (Hughes et al. 2011). It seems, therefore, that attentional capture by a deviant stimulus is diminished when encoding conditions are difficult. There is little reason to suppose, however, that high load precluded serial rehearsal, thus the key precondition for the changing-state effect remained.

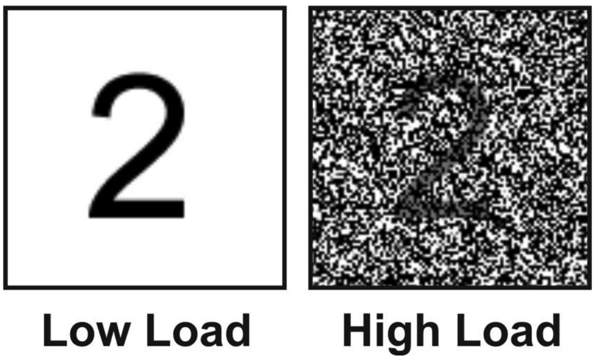


**Figure 3:** Illustration of the encoding load manipulation. Visually degraded stimuli (right panel) were set to a transparency of 50 % and embedded in static visual noise.

### iv) Deviation and changing-state effects have a different cognitive locus

There is other work showing that deviation and changing state effects are quite distinct and separte phenomena. Experiments in which the timing of the presentation of the irrelevant sound in relation to the task differs suggest as much. Two conditions are typically contrasted, one in which the presentation of the sound is restricted to the time during which the to-be-remembered items are being presented or to a retention stage located between the last item and a cue (some 10 s later) to recall the list. Miles et al. (1991) showed that changing-state irrelevant sound has a similar disruptive effect at both stages of the task. The most plausible explanation is that changing-state stimuli interfere with serial rehearsal (the factor common to both stages of the task), not stimulus encoding (a factor characteristic only of the presentation stage). When a temporal deviant (one item delayed in time relative to the others) was embedded in an irrelevant sequence confined to the presentation stage, it exerted its usual disruptive effect. However, as shown in Figure 4, no such effect was evident when the sound coincided only with the retention stage (Hughes et al. 2005). This is entirely in line with the idea that deviants act through encoding and changing state acts through rehearsal.

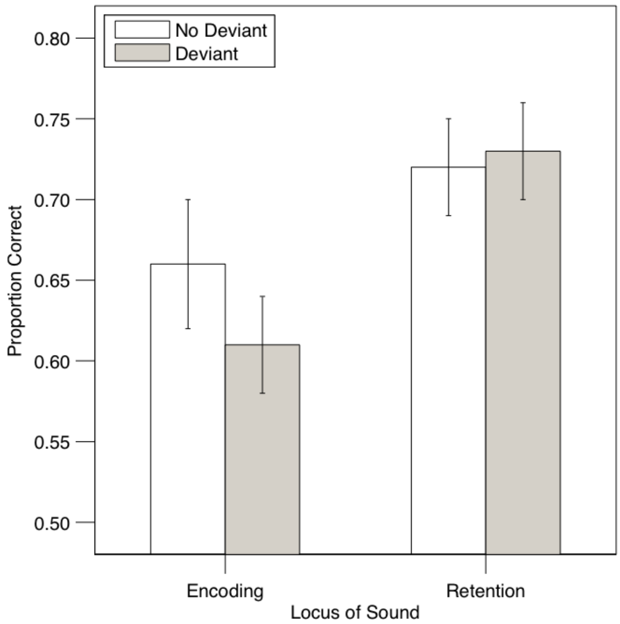


**Figure 4:** Proportion of items correctly recalled in a serial recall task according to whether an irrelevant sound sequence was presented during encoding only or during retention only and whether or not it contained a (temporal) deviant. Adapted from Experiments 1 and 2 of Hughes et al. (2005)

## CONCLUSIONS AND PRACTICAL IMPLICATIONS

Like all the research using methods of the sort we have just described, the key message is that not very loud sound can have an appreciable impact on cognitive performance. Just how these laboratory results translate into effects in everyday life is by no means certain, but we do know from our own work that sounds of modest intensity can be distracting. So, it might be that such effects also impair efficiency in real-world safety-critical tasks or highly skilled work. This by-now substantial body of laboratory evidence is yet to be acted on by those whose primary interest is in abatement however. For this constituency of noise researchers, noise level seems to be the main pre-occupation in spite of this evidence. The particular studies we have reviewed here have further refined our understanding of distraction. Evidence is accumulating that there are two types: one from unexpected sounds that seems to be due to a violation of a pattern already built up. The registration of stimuli seems to be particularly vulnerable to this effect. We know too that this type of distraction can be resisted by the person who hears it, such as by giving a warning that it is going to appear as well as by increasing effort on the prevailing cognitive activity (Hughes et al. 2011). This suggests that requiring the listener to increase their concentration will have beneficial effects. The other type of distraction occurs when changing sounds are heard in sequence. This is far more enduring and robust—it does not habituate and increased concentration does not help—and it seems more related to what is happening within the cognitive system when we are planning actions related to language such as speaking, reading and remembering. Again, it is worth emphasising that this effect is not related to the intensity of the sounds (the sounds are typically about 60 dBA). Knowing there are two types of response to low-intensity sound extends our knowledge of how distraction works. One of the challenges of the future is to see how these effects can be traced beyond the laboratory, to the classroom, the home and the office to explore in what ways our everyday experiences are shaped by auditory distraction.

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# The importance of meaning in ambient speech to eliciting cognitive performance effects

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## INTRODUCTION

In open-plan offices employees have to perform demanding cognitive tasks in the presence of ambient speech due to conversations among colleagues or colleagues being on the phone. Ambient speech has been shown to impair cognitive performance at silent, concentrated work in laboratory studies. This holds true even if the background speech is irrelevant to the task at hand and is intended to be ignored by the listener. Many cognitive psychology experiments demonstrated this phenomenon, which is best explored in tests of verbal short-term memory, such as remembering a series of digits (see Hellbrück & Liebl 2008, for a summary). However, office work is far more than remembering single items in their correct order. A more typical example of office work is reading and text comprehension, as often written information needs to be processed and elaborated. Here, not only the serial order of the words needs to be stored, but the relation between the words must be elaborated to understand and derive information. Irrelevant background speech has been shown to impair performance in reading and text comprehension tasks (e.g. proofreading: Jones et al. 1990; Miles et al. 1988; reading comprehension, or text recall: Martin et al. 1988; Oswald et al. 2000). In these studies, however, the special importance of semantic content within ambient speech is striking; specifically, that irrelevant but semantically meaningful speech (e.g. mother tongue) reduced performance to a greater extent than semantically neutral speech (foreign language or reversed speech). In contrast to that, the semantic content of ambient speech is irrelevant to the extent of performance effects in tasks that solely rely on serial verbal short-term memory (e.g. Colle & Welsh 1976; Jones et al. 1990).

This pattern of results is explained by the 'interference by process' principle (e.g. Macken et al. 1999). This principle is based on the assumption that performance reducing sound effects arise due to the similarity of processes involved in the voluntary processing of the task on the one hand and the automatic and involuntary processing of ambient speech on the other hand. Because proofreading, text recall and reading comprehension require semantic processing, the semantic content of the background speech contributes to its detrimental impact. Analogously, the semantic content of background speech plays no role in tasks with minimal load on semantic processing like, for example, verbal serial recall. Here, unrelated verbal items (e.g. digits, consonants, words) are presented successively and have to be recalled afterwards in exact presentation order. This strict serial reproduction criterion ensures that successful task performance is achieved without semantic processing of the memorized items. Accordingly, mother tongue reduces serial recall performance to the same extent than unknown foreign language (e.g. Colle & Welsh 1976; Jones et al. 1990).

The present study consists of two experiments which tested the 'interference by process' principle (e.g. Macken et al. 1999) with respect to semantics by systematically varying both task characteristics and semantic content of background speech signals. The extent to which successful task performance relied on semantic processing was varied by using a reading comprehension task consisting of two subtasks. These subtasks differed regarding to the need to semantically process the presented information. The semantic content of background speech was varied differently in the two present experiments. In Experiment 1, the reading comprehension task had to be solved during semantically meaningful background speech (i.e., mother tongue) and during semantically neutral speech (i.e., foreign language). In Experiment 2, the semantic content of background speech was varied by step-wise reducing the coherence of mother tongue background speech. Here, coherent text, unrelated sentences, multiple word phrases (e.g. a rainy day, the girl’s dress) or unrelated words were played-back.

## EXPERIMENT 1

The reading task used in the present study is based on the German version of the reading span task (Daneman & Carpenter 1980) provided by Hacker and co-authors (Hacker et al. 1994, 2002). The present task comprises two subtasks that vary regarding to the extent to which they rely on the semantic processing of the presented information. Participants read four unrelated sentences. Afterwards, they are asked to recall the last word of each sentence (word recall). Then, four paraphrases of the four initial sentences are shown. Participants are asked to verify whether the information given in the to-be-remembered sentence (e.g. ‘The judge went down the footbridge and jumped into the sea.’) is represented in the paraphrase (e.g. ‘The man jumped into the water.’) or not (e.g. ‘The judge jumped into the car.’). This sentence verification task cannot be solved without semantic processing of the to-be-remembered sentences. Less semantic processing is, however, necessary to solve the word recall task in which the last word of each of the read sentences is to be recalled (in this example: ’sea’).

Accordingly, we expected semantically meaningful speech to reduce performance in the sentence verification task significantly more so than semantically neutral speech. In the word recall task, however, we expected background speech to reduce performance irrespectively of its semantic content.

### Methods

32 students from the Catholic University of Eichstätt-Ingolstadt participated in Experiment 1 (*M* = 22.4 years, 19-29 years, 26 female, 6 male). All participants reported normal hearing and received a small allowance.

Four different sound conditions were included in Experiment 1. Narration in a foreign language was used as semantically neutral speech by ensuring that subjects did not know the chosen language. Unrelated sentences in the participants’ mother tongue were used as semantically meaningful background speech. These two speech conditions were played back at $L_{eq}$ = 55 dBA. A silence condition (pink noise at $L_{eq}$ = 28 dBA) was included as an overall control condition to measure performance at baseline. Furthermore, the semantically meaningful speech was played back at $L_{eq}$ = 35 dBA and, thus, was as loud as soft whisper. This condition was included since research has found that in a serial recall task (i.e., a simple reproduction task), the detrimental impact of background speech does not vary with its level (Colle 1980; Tremblay & Jones 1998).

In a trial of the reading comprehension task, four sentences were presented one after the other. Following these presentations, the two subtasks, word recall and sentence verification, were completed as described above. Twelve of these four-sentence trials had to be solved in a sound condition before the next sound condition with twelve more four-sentence trials of the reading task began. Succession of sound conditions was balanced over participants.

## Results

The left panel of Figure 1 depicts mean error rates in the word recall task for each sound condition. Recall performance is significantly reduced during all speech condition compared to silence as t-tests verify ($p < .001$, two-tailed). Since speech conditions do not differ significantly from each other ($p \geq .157$, two-tailed), no differences in disturbance impact are found between semantically neutral and meaningful speech, or between loud and soft meaningful speech.

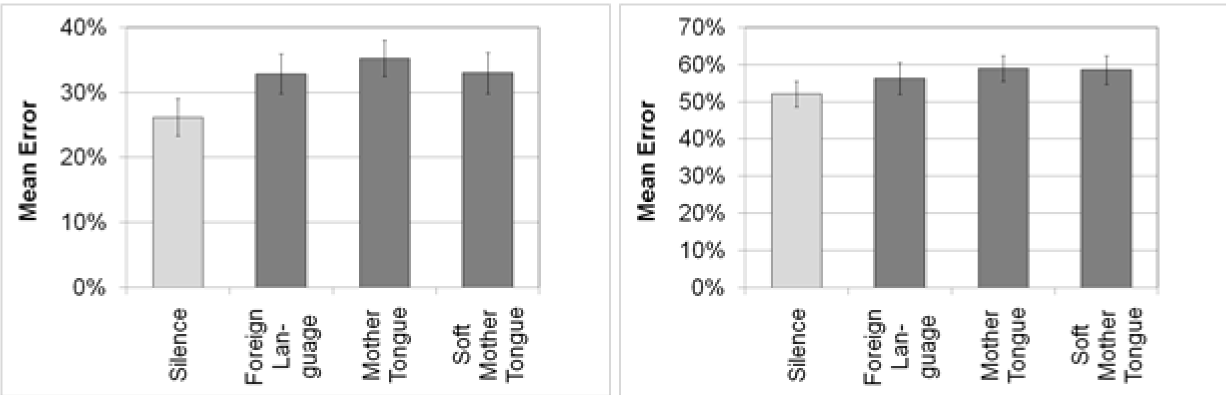


**Figure 1:** Impact of semantically meaningful speech (mother tongue) and semantically neutral speech (foreign language) on word recall performance (left panel) and sentence verification (right panel) in Experiment 1 ($n$=32). Error rate means with standard errors are plotted.

In contrast, semantically neutral speech (foreign language) reduces performance in the sentence verification subtask not significantly compared to silence ($p = .190$, two-tailed; Figure 1, right panel). Yet semantically neutral speech also does not differ significantly from meaningful speech conditions ($p \geq .376$), which reduce sentence verification significantly compared to silence ($p \leq .039$, two-tailed).

## EXPERIMENT 2

In Experiment 2, the semantic content of background speech was reduced step-wise by reducing the coherence of the speech signal from coherent text to unrelated sentences to multiple word phrases and, finally, to unrelated words. According to the 'interference by process' principle (e.g. Macken et al. 1999, cp. Introduction), we expected performance in the sentence verification task to vary with the coherence of background speech due to the task's reliance on semantic processing. In the subtask 'word recall,' however, speech conditions are expected to reduce performance irrespectively of their coherence since semantic processing is not necessary for successful task performance in this condition. Since the latter sound effect pattern has been already verified for serial recall performance (e.g. Colle 1980; Ellermeier & Hellbrück 1998), we also included this task in Experiment 2.

## Methods

24 students of the Catholic University of Eichstätt-Ingolstadt, Germany, participated in the experiment. All participants reported normal hearing and received a small allowance.

Performance was tested during six sound conditions: one silence condition (pink noise at $L_{eq}$ = 25 dBA), which served as performance baseline, and five background speech conditions. The latter consisted either of coherent text, unrelated sentences, multiple word phrases, or unrelated words. Additionally the coherent text recording was superimposed with pink noise of equal level (signal-to-noise ratio, SNR = 0 dBA). To note, speech intelligibility remained perfect in this ‘text control’ condition and the semantic content of this speech signal was not reduced. All background speech conditions were presented at $L_{eq}$ = 55 dBA.

The same reading task was used as in Experiment 1. Additionally, a verbal serial recall task was included. Here, the digits 1 to 9 were presented successively in a randomized order during the different background sound conditions. The participants were asked to recall the numbers after a short retention interval of 10 s in their exact presentation order.

Participants began with the serial recall task and after completing this task during all sound conditions, the reading task followed. Here, twelve four-sentence trials (cp. Experiment 1) were performed during a sound condition before the next sound condition started and the additional twelve trials were completed. Succession of sound conditions was counterbalanced over participants.

## Results

In the serial recall task, each digit not recalled at its previously presented position is counted as an error. Mean errors are depicted in the left panel of Figure 2 for each sound condition. T-tests verify that all background speech conditions result in significantly more errors compared to silence ($p < .001$, two-tailed). This holds true independently of coherence of background speech, i.e. background speech conditions differ not significantly from each other ($p \geq .108$, two-tailed).

The same result pattern is observed for word recall performance (Figure 2, right panel). Here, error rates are significantly higher during all speech conditions compared to silence ($p < .001$, two-tailed). Error rates during unrelated sentences are in tendency higher than during unrelated words, multiple word phrases and ‘text control’ ($.053 \leq p \leq .103$, two-tailed) while all other comparisons between speech conditions are non-significant ($p \geq .280$, two-tailed).

Finally, analyzing performance in the sentence verification task reveals an unexpected non-effect of background speech conditions. Pooling error rates over all participants results in mean error rates between M=36 % and M=39 % per sound condition. According to this, there are no significant differences between sound conditions: speech conditions neither differed significantly from silence ($p \geq .27$, two-tailed) nor from each other ($p \geq .29$, two-tailed).

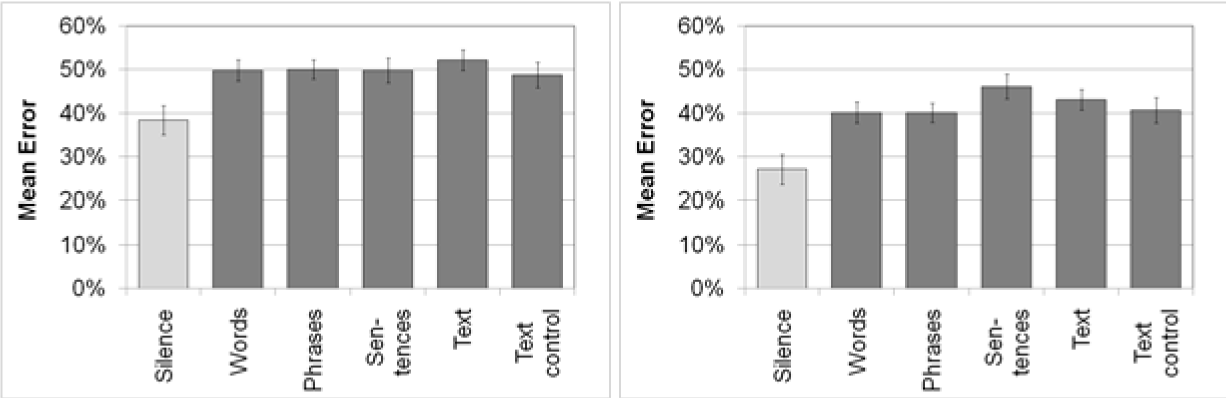


**Figure 2:** Impact of speech conditions varying in coherence on serial recall performance (left panel) and word recall (right panel) in Experiment 2 (*n*=24). Error rate means with standard errors are plotted.

## CONCLUSIONS

At many office workplaces employees must perform verbal tasks, such as reading or writing text. Often they must do so in the presence of background speech due to conversations or phone calls among colleagues. The interference by process principle (e.g. Macken et al. 1999; cp. Introduction) suggests that a background sound reduces performance if the cognitive processes involved in the voluntary processing of the task compete with the automated processing of the ambient sound. Two experiments tested the interference by process principle with respect to semantic processing. Therefore the semantic content of ambient speech was varied as well as the extent to which performance in a given task relied on semantic processing. For experimental realization of the latter aspect, a reading span task encompassing two subtasks was used. These subtasks differed regarding the necessity of semantic processing for successful task performance: Whereas the subtask ‘word recall’ did not require semantic processing, the subtask ‘sentence verification’ could not be solved without semantic processing of the presented text. The semantic content of background speech was varied by playing-back mother tongue compared to foreign language (Experiment 1) or by step-wise reducing mother tongue’s coherence from stringent text to unrelated words (Experiment 2).

The result pattern of Experiment 1 is in line with the interference by process principle. Semantically meaningful speech (i.e., unrelated sentences in mother tongue) reduced performance in the sentence verification subtask significantly in contrast to semantically neutral speech (i.e., narration in foreign language). In the subtask ‘word recall’, however, the two speech conditions caused a similar decline of performance compared to silence. Thus, the detrimental impact of background speech only varied with its semantic content if task performance relied on semantic processing. These findings of Experiment 1 also comply with the extant literature. Several studies verified that semantically meaningful background speech impairs reading comprehension and performance in other complex verbal task significantly more so than semantically neutral speech (e.g. Jones et al. 1990; Miles et al. 1988; Martin et al. 1988; Oswald et al. 2000). On the contrary, the detrimental impact of background speech on simple reproduction tasks has been shown to be independent of its semantic content (e.g. serial recall; cp. Colle 1980; Ellermeier & Hellbrück 1998).

Experiment 2 was based on a step-wise reduction of the semantic content of background speech by reducing its coherence from stringent text, to unrelated sentences, to multiple word phrases, and, finally, to unrelated words. As expected, all speech conditions significantly reduced performance in the subtask ‘word recall’; however, speech conditions did not significantly differ from each other. This pattern of results was also found in the included serial recall task. All background speech conditions reduced performance significantly in this pure reproduction task, irrespective of the coherence of the background speech signal. In contrast to Experiment 1, however, background speech did not affect performance in the sentence verification subtask and, thus, reading comprehension. This surprising non-effect might be due to a small effect size of the disturbance impact of background speech on reading comprehension tasks. Thus, the effect might not show up when relatively small samples sizes are tested ($n$ = 24 in Exp. 2 compared to $n$ = 32 in Exp. 1).

The presented results do not fully support the ’interference by process’ principle (e.g. Macken et al. 1999). However, Experiment 1 provides some evidence for the special role of the semantic content of background speech for its impact on reading comprehension. This experimental results are consonant with extent studies which also corroborate that performance in complex verbal tasks is impaired less if the semantic content of background speech is reduced (e.g. Jones et al. 1990; Miles et al. 1988; Martin et al. 1988; Oswald et al. 2000).

These empirical findings may provide a hint towards an approach to deal with acoustic disturbance in offices. In open-plan offices employees have to accomplish cognitive tasks in the presence of background speech. Reducing the intelligibility of background speech – e.g. by masking – may help employees to perform better. Reduced speech intelligibility implies that fewer words are understood compared to a highly intelligible speech signal indicated by high word identification rates. Considering that one or even several words that are crucial for the extraction of a sentence’s informational content are not understood, less intelligibility can be equated with a diminished semantic content of the background speech signal (e.g. ‘__ go to __ in __.’ or ‘We go to __ in July.’ instead of ‘We go to London in July.’). Venetjoki et al. (2006) provide experimental evidence for these assumptions since these authors found less intelligible background speech to have less negative effects on proofreading compared to highly intelligible speech.

## ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Prof. Dr. Jürgen Hellbrück for providing all facilities for experimental testing and to Sebastian Backe for his work on the stimuli for the reading task.

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# Room acoustics and work performance - experimental study in a full-scale open-plan office laboratory

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## SUMMARY

The aim of the study was to show that the room acoustic design of an open-plan office that contains speech sounds has an effect on cognitive work performance, acoustic satisfaction and perceived workload. The study was carried out in an open-plan office (90 $m^2$). Four acoustic conditions, with different speech privacy levels, were built. The conditions were created by changing the acoustic environment using screens, absorbers, and a speech masking system. Speech was produced from empty workstations. In addition, a silent condition was used as a reference condition. Altogether 119 subjects participated in the experiment (a between-groups design). Subjects were exposed to the acoustic condition for nearly 4 hours. Performance was measured with several cognitive tasks which are essential for many kinds of office work. Questionnaires were used to gather information on acoustic satisfaction and subjective workload. The silent condition was the most beneficial acoustic condition. The condition with the lowest speech privacy was the least beneficial. The experiment has high practical relevance for the acoustic design guidelines as the acoustic conditions of this experiment can be realized in open-plan office workplaces.

## INTRODUCTION

According to Hongisto (2005), cognitive performance decreases with increasing speech intelligibility. The result has high practical significance as it promotes noise control in open-plan offices where irrelevant speech is the most significant indoor environment problem (e.g., Kaarlela-Tuomaala et al. 2009). Speech intelligibility can be predicted very reliably by measuring the Speech Transmission Index, STI, between the speaker and listener. STI ranges between 0.00 and 1.00, with the highest values indicating perfect speech intelligibility and low speech privacy. In open-plan offices, a low STI (i.e. high speech privacy) is desirable in areas where tasks requiring high concentration and confidential conversations take place. STI can be reduced by reducing the signal-to-noise ratio of speech. This is done by reducing the level of speech (absorption, screens) and by increasing the background noise level up to 45 dBA (speech masking).

In previous experimental work (see review in Haka et al. 2009) the manipulation of STI has been done by electrical means. That is, different STI levels have typically been realized simply by changing the signal-to-noise ratio of speech. In these experiments, the STI (or speech intelligibility) has been kept constant during each sound condition. However, the STI strongly depends on the distance of the speech source (Figure 1). Therefore, an exact STI value cannot be determined for an open-plan office but it varies depending both on room acoustic conditions and the distance between a speaker and a listener. Literature lacks an experimental study where the exposure to speech is implemented using realistic open-plan office conditions where

STI varies with time depending on the distance to the speakers and the room acoustic design.

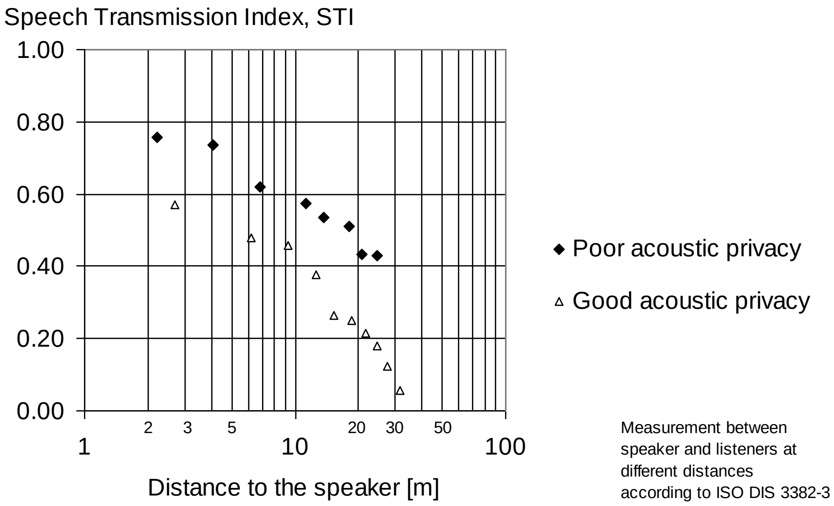


**Figure 1:** Typical shape of the STI vs. distance -curve in two extreme acoustic conditions measured in open-plan offices (Virjonen et al. 2009)

The aim of the study was to show that the room acoustic design of an open-plan office containing speech sounds has an effect on cognitive work performance, acoustic satisfaction and perceived workload. The experiment was carried out in an open-plan office laboratory, where four room acoustic conditions (speech privacy levels) were built. Speech effort was constant in all four conditions. Silence was included as the fifth condition and used as a reference point.

## MATERIALS AND METHODS

### Subjects

A total of 119 university students (90 female, 29 male) took part in the study. Subjects were 19 to 35 years old (mean=23.2, SD=3.2) and native Finnish speakers. None of the subjects had dyslexia or reported any hearing difficulties.

### Laboratory room

The experiment was carried out in a laboratory which resembled a normal open-plan office (Figure 2). The room contained 12 workstations. Six were occupied during this experiment. The room dimensions are 8.9x9.4x2.55 m. The environmental factors (airflow rate, thermal conditions, lighting) fulfilled the optimum target values for office work.

### Acoustic conditions and sounds

Five acoustic conditions were tested and are described in Table 1. The data is based on an extensive room acoustic experiment carried out in the same room (Keränen et al. 2011). The speech environment was designed to resemble an environment where four speakers are talking to the phone (one speaker at a time). The speech was produced from four loudspeakers placed in the corner workstations (Figure 2).


**Figure 2:** Laboratory layout in the acoustic conditions 1 and 3 (top), and 2, 4 and 5 (bottom)

**Table 1:** Descriptions of the acoustic conditions

| | **Acoustic condition** | | | | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| **Full room acoustic description** | **No damping, no masking** | **Damping, no masking** | **No damping, masking** | **Damping, masking** | **Silence** |
| **Expected acoustic privacy** | Poor | Moderate | Moderate | Good | Perfect |
| **Treatment of the room** | | | | | |
| Ceiling absorption performance: | Low | High | Low | High | High |
| Wall absorption performance: | Low | High | Low | High | High |
| Screen absorption performance: | Low | High | Low | High | High |
| Masking sound level [dBA] | 37 | 33 | 45 | 45 | 35 |
| Screen height [m] | 1.3 | 1.7 | 1.3 | 1.7 | 1.3 |
| Side screens installed: | No | Yes | No | Yes | Yes |
| Presence of speech sounds: | Yes | Yes | Yes | Yes | No |
| **Speech acoustic descrptions averaged over all workstations** | | | | | |
| Speech Transmission Index STI | 0.60 - 0.70 | 0.42 - 0.80 | 0.45 - 0.59 | 0.09 - 0.51 | 0.00 |
| Speech level [dBA] | 50 - 53 | 37 - 50 | 50 - 53 | 37 - 50 | 0 |

The speech was obtained from 6 separate radio programs. In each of them, four people were debating about a topic of common interest. Five recordings, lasting approximately 30 minutes each, were edited from these. These recordings were played in the room during each test session in the same order. During each recording, the same speaker was talking about one topic in one corner. The purpose was to make it sound like one side of a phone conversation. However, the speaker for each corner was taken from a different radio program so that the topic of each speaker was different. One corner was speaking for 5 to 25 seconds which was followed by a break of 1 to 8 seconds before the next corner started to speak. The order of the corners was pseudo-randomized so that the amount of audio material presented from each corner was constant. The speech effort was between normal and casual speech effort. The A-weighted level was 55.0 dB measured at 1 meter distance in a free field. The speech was produced by a loudspeaker having mouth-like directivity. The height was 1.2 meters from the floor. The sound power level of speech was constant in every acoustic condition. The sound power level of each sentence was adjusted to the same level.

Masking sounds were produced from 14 loudspeakers placed above the suspended ceiling. The spectrum of masking was equalized between acoustic conditions. The masking sound was pink noise filtered to -5 dB/octave within 100 – 10,000 Hz. The variation of masking level was below 1.0 dB between workstations.

### Questionnaires and performance tests

The measure for working memory capacity was modified from the original **operation span task** developed by Turner and Engle (1989). It consisted of equation-word pairs. First, an equation (e.g., 5 x 4 + 8 = 30) appeared on the computer screen and the subject had to decide whether it was true or false by clicking the appropriate option on the computer screen. After this, a word to be memorized was presented for 2 s. This was followed by another equation-word pair. After all the pairs in one set had been presented, the subject was asked to type in all the words. Subjects were instructed to aim at over 85 % accuracy on equations, and received feedback on this after typing each word list. The size of equation-word sets varied between three and seven pairs, and the sets were presented in a random order. Subject's working memory capacity was defined as the sum of correctly recalled items from all word lists (partial-credit load scoring, see Conway et al. 2005). Correct serial positions within lists were not required and minor misspellings were accepted, if unambiguous. The maximum score was 50.

The same task was used as **a working memory task** with the following changes. The words and equations were different. The set size varied from three to eight, the sets were presented in a gradually growing order, and the maximum score was 58. Three matching versions were used.

In the **N-back task** (e.g. Owen et al. 2005), the subjects were presented with a sequence of letters on a computer screen. In 0-back, subject's task was to identify the target letter 'X' by pressing YES or NO for each stimulus. In 1-back, the task was to respond whether the presented letter was identical to the one immediately preceding it (i.e. one trial back). In 2-back, the task was to respond whether the presented letter was identical to the one presented two trials back. Each set contained 30+n letters (n = 0, 1 or 2) in a pseudorandom order. 30 % of letters were targets. Upper case and lower case was varied to prevent subjects from relying on visual recognition only. The whole task included three sets of each difficulty, i.e. altogether 9 sets. The order of sets was counterbalanced across subjects and test blocks. Three different versions were created. Response accuracy (%) and reaction times (ms) were measured.

Three questionnaires were used (a questionnaire for background information, NASA-Task Load Index and an acoustic satisfaction questionnaire). A questionnaire for background information included questions on age, gender, the amount of sleep during the preceding night, noise sensitivity and current factors that might impede performance. Noise sensitivity was assessed with 5 items from Weinstein (1978) and 4 items (the subscale 'work') from NoiSeQ-R (Griefahn et al. unpublished data). The items were averaged together to form a sum variable (Cronbach's α .85). NASA-Task Load Index (NASA-TLX; Hart & Staveland 1988) was used as a measure of subjective workload after each task. It includes six bipolar scales: mental demand, physical demand, temporal demand, perceived performance, effort and frustration level. The dimensions are rated on a scale from 0 to 100. At the end of the experiment, the subjects filled in a questionnaire on acoustic satisfaction and subjective effects of noise. Many of the items had been used in our previous study (Haapakangas et al. 2011). A sum variable for acoustic satisfaction was formed from 9 items (Cronbach's α between .71 and .88 in speech conditions and .60 in silence).

## Experimental design, procedure and statistical analyses

The study had a mixed design with acoustic condition as a between-groups variable and the test block as a within-subjects variable. The sound condition had to be tested with independent groups because some of the sound conditions required construction of the room so it would have been impossible to present the conditions in different orders for different people. A measure of working memory capacity was included as a covariate in the analysis of the working memory task. Noise sensitivity was used as a covariate in the analyses of NASA-TLX and acoustic satisfaction.

The experimental procedure is shown in Figure 3. Four to six subjects were tested at the time. All experiments took place at the same time of day, starting at 9.30 a.m. The experiment lasted for 4 hours. The experimenter was present at all times.

Data was analysed with SPSS 18.0. Mixed model ANOVA and analysis of covariance (ANCOVA) were used in the analyses. Benjamini-Hochberg adjustments were made to all paired comparisons. In the N-back task, subject whose performance differed more than 3 SD from the group means were excluded. In working memory task, subjects whose accuracy on the equations in the WM capacity measure was below 75 % were excluded from the analyses.

| | | | | | |
|---|---|---|---|---|---|
| Information in another room | | 20 min | **Block B** | | 60 min |
| | | | SR | | |
| **Working memory capacity task** | | 12 min | LTM1 | | |
| **Practice block** | | 20 min | NB | | |
| Questionnaire 1 | | | WM | | |
| SR, NB, LTM1, IGT, LTM2, NASA-TLX | | | LTM2 | *NASA-TLX after each task* | |
| Short break (voluntary) | | 3 min | Short break (voluntary) | | 3 min |
| **Block A** | | 40 min | **Block C** | | 60 min |
| SR | | | SR | | |
| NB | | | NB | | |
| WM | *NASA-TLX after each task* | | WM | | |
| Break (obligatory for all) | | 10 min | IGT | *NASA-TLX after each task* | |
| | | | Questionnaire 2 | | |

**Abbreviations and task durations**

| | |
|---|---|
| SR = serial recall, 7 min | IGT = Iowa gambling task |
| NB = N-back, 18 min | LTM1 = long term memory, reading phase, 10 min |
| WM = working memory task, 12 min | LTM2 = long term memory, recall and write phase, 5 min |

**Figure 3:** Experimental procedure of the test session

## RESULTS

### Working memory performance

A 5 (acoustic condition) x 3 (test block) analysis of covariance (ANCOVA) with working memory capacity as a covariate, showed a main effect of acoustic condition ($F_{4,110}$ = 3.53, partial $\eta^2$ = .11, $p$ =.009). Paired comparisons revealed that condition 5 differed from condition 1 ($p$=.01) and condition 3 ($p$=.02). The acoustic conditions 1-4 did not differ statistically from each other (Figure 4a).

There was also a statistically significant main effect of test block ($F_{2,220}$ = 4.32, partial $\eta^2$ =.038, $p$=.014), showing a slight improvement in performance towards the end of the test session. However, there was no interaction between acoustic condition and test block ($p$ >.5) indicating that the effect of time on performance was similar in all acoustic conditions.

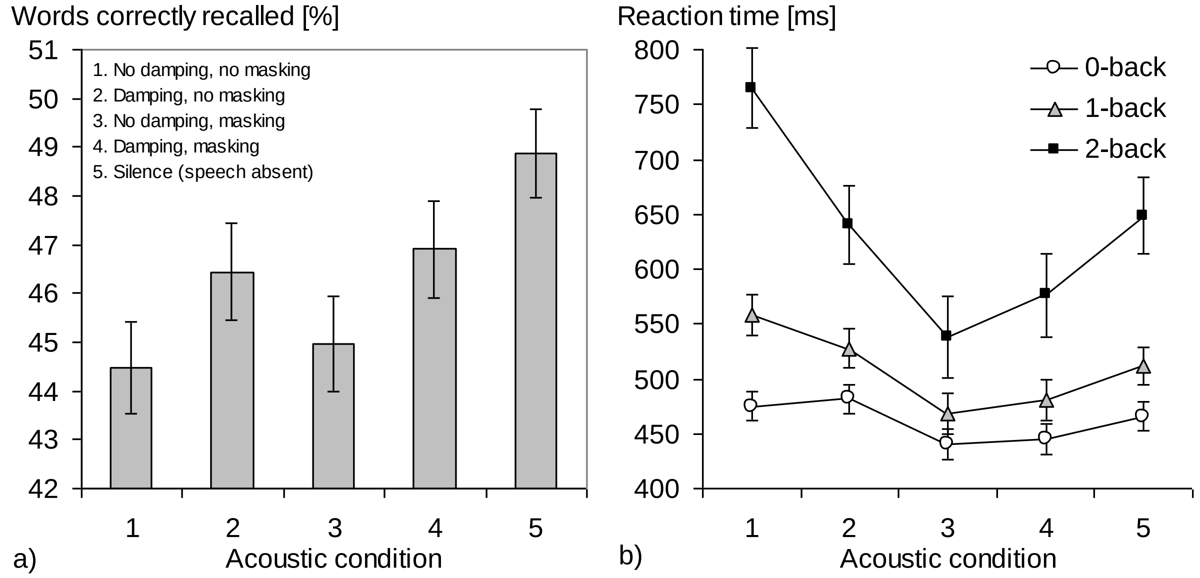


**Figure 4:** a) Adjusted means and standard deviation for working memory performance, noise sensitivity as a covariate. b) Reaction times in the N-back task (three levels of difficulty) in the five acoustic conditions. Means and standard errors.

### N-back task

A 5 (acoustic condition) x 3 (N-back level) x 3 (test block) x 3 (task block) repeated measures ANOVA was conducted for the RTs and accuracy. For accuracy, the blocks of each n-back level were collapsed together because the effect of task block was not significant. The analyses showed no effect of acoustic condition on accuracy ($p$ = .59). However, the RTs were significantly affected by acoustic condition ($F_{4,106}$= 4.89, partial $\eta^2$ =.16, $p$=.001). Paired comparisons showed that reaction times were slower in condition 1 compared to conditions 3 ($p$<0.001) and 4 ($p$=0.005). This means that although the subjects were able to maintain a similar level of accuracy, it required more cognitive effort in condition 1. There was also an interaction between acoustic condition and N-back complexity ($F_{4,116}$=4.76, partial $\eta^2$ =.15, $p$=0.001, Figure 4b), indicating that the differences between acoustic conditions emerged when cognitive demands increased.

## Subjective perceptions

Each dimension of the NASA-TLX was separately analysed with a 5 (acoustic condition) x 3 (test block) analysis of covariance (ANCOVA) with noise sensitivity as a covariate. In the working memory task, there was a statistically significant effect on mental demand ($F_{4,113}$=3.10, partial $\eta^2$=.10, $p$=.018), Figure 5a. Mental demand was lowest in condition 5 which differed significantly from condition 1 ($p$=.03) and conditions 2 ($p$=.25). In the N-back task, there were no effects of acoustic condition on any of the subscales in NASA-TLX (p>.09).

Acoustic satisfaction was statistically significantly affected by acoustic condition ($F_{4,113}$=44.3, partial $\eta^2$=.61, $p$<0.001, Figure 5b). All paired comparisons were statistically significant ($p$≤0.009), except for the pairs 1 vs. 2, and 3 vs. 4.

Ratings of different noise sources present in the office room are presented in Figure 6. The ratings show that the acoustic design had an effect mainly on the voices coming from the more distant workstations. The results are summarized in Table 2.

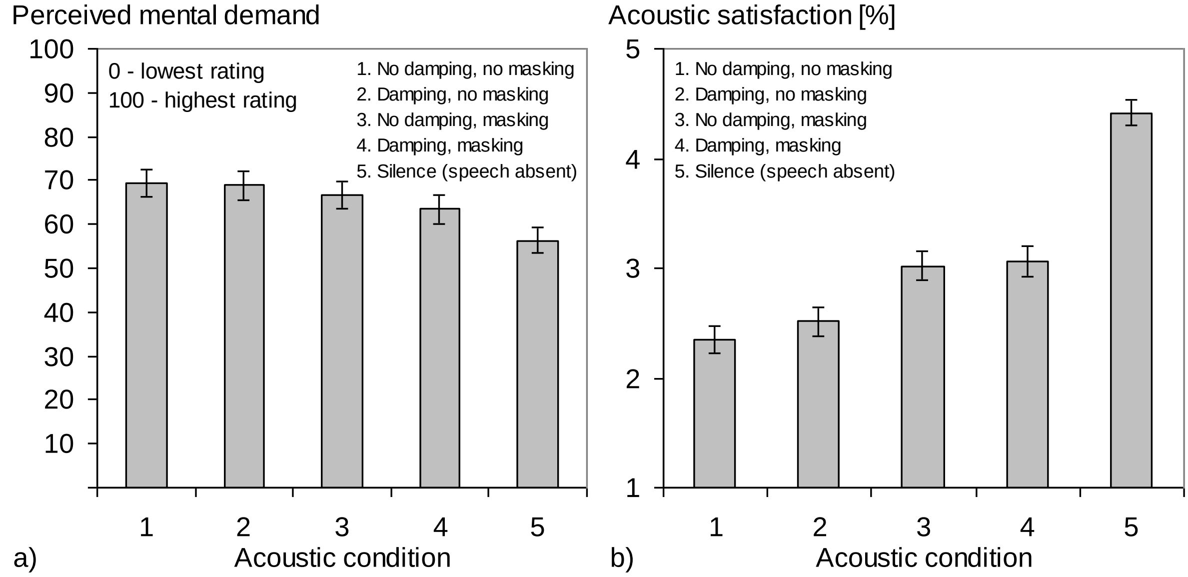


**Figure 5:** Adjusted means and standard errors, noise sensitivity as a covariate.
a) Perceived mental demand in the working memory task. b) Acoustic satisfaction in five acoustic conditions. Scale: 1 - low satisfaction, 5 - high satisfaction.

**Table 2:** The summary of statistically significant findings. Sign "-" means significant decrement compared to the indicated acoustic condition and sign "+" significant improvement. Empty cells indicate non-significant findings.

| | 1 No damping no masking | 2 Damping no masking | 3 No damping masking | 4 Damping masking | 5 Silence |
|---|---|---|---|---|---|
| Working memory performance, compared to 5 | - | | - | | |
| N-back reaction time, compared to 1 | | | + | + | |
| Perceived mental demand, compared to 5 | - | - | | | |
| Acoustic satisfaction, compared to 5 | - | - | - | - | |
| Acoustic satisfaction, compared to 4 | - | - | | | + |
| Acoustic satisfaction, compared to 3 | - | - | | | + |
| OVERALL RANKING ORDER | 5 | 4 | 3 | 2 | 1 |

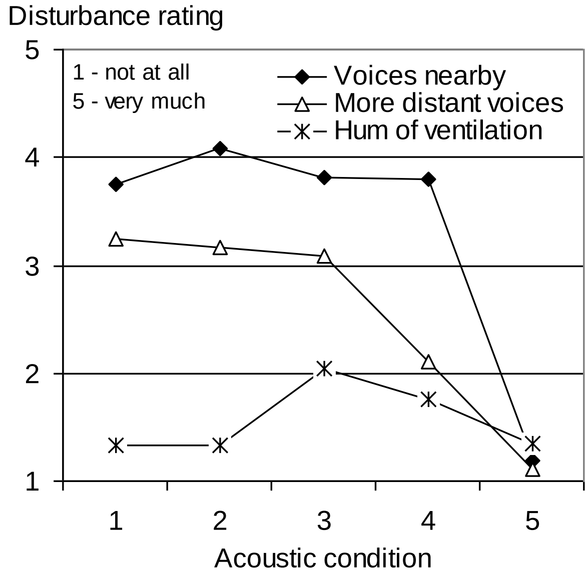


**Figure 6:** Mean disturbance of sounds in during the experiment

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# Impact of Intensive Care Unit noise on nurses

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## ABSTRACT

Effective intensive care units (ICUs) require a complex choreography of nurse tasks and architectural acoustic design that is only beginning to be understood. Unfortunately, the sound environments of many hospital settings, including ICUs, often fall far short of supporting the underlying mission of hospitals. There is strong and growing evidence that ICU soundscapes impact staff health, stress, and performance. This paper discusses a series of studies conducted by the Healthcare Acoustics Research Team (HART) that focus specifically on the impact of ICU noise on nurse outcomes. In one phase, two ICUs with similar patient acuity but differing architecture were compared via objective acoustic measures and nurse questionnaires. Although overall sound levels in the two wards were essentially identical, nurse perception varied greatly. More detailed analysis revealed that nurse response was correlated with the occurrence rate of peak and maximum sound levels in the units. A follow-up phase looked more closely at the association between healthcare sound environments and specific caregiver tasks such as auditory monitoring of patients. In another phase, results from ICU nurse surveys were compared to other personnel groups with similar distributions of gender, education, and age from non-ICU healthcare settings, offices, and pre-schools. This phase further investigated the relationships between the sound environment and nurse stress symptoms such as auditory or mental fatigue, tension, and irritation. Taken as a whole, these studies provide new insight into the impact of hospital acoustics on nurses and potential steps to improve the sound environment.

## INTRODUCTION

Intensive care units (ICUs) house some of the most critically ill patients in hospitals and thus present a high demand on nurses. Mortality rates among ICU patients range between 10 % to 20 % and ICU nurses must often make critical life and death decisions (SCCM 2006). The auditory environment, or "soundscape" in ICUs is important for many reasons: patients need a relaxing environment that promotes healing and rest while staff need an environment supportive of task performance and speech communication. Achieving an effective ICU soundscape requires a complex choreography of nurse tasks and architectural acoustic design that is only beginning to be understood.

The Hospital Acoustics Research Team (HART) was formed to provide insight into hospital soundscapes using an interdisciplinary perspective. HART is a collaboration of specialists from various universities, medical facilities, and industries with expertise in engineering, architecture, psychology, medicine, and nursing. The goal of HART is to evaluate the modern hospital soundscape, its impact on occupants, and avenues for improvement.

This paper will highlight HART research results, provide an overview of the occupational considerations for ICU nurses including the potential impacts of the soundscape on nurse perception. Although this paper is focused on the effects of the ICU soundscape on nurses in particular, detailed information about potential impacts of hospital soundscapes on patients can be found in sources such as Busch-Vishniac et al. (2005) or Ryherd et al. (2008).

## The ICU environment

ICUs can differ based on their specialty (i.e., multispecialty, single specialty). In multispecialty ICUs such as Medical-Surgical units, patients with a wide spectrum of illnesses are treated. Specialty ICUs focus on patients with similar problems or specific diseases such as newborns (Neonatal-ICU), children (Pediatric-ICU), cardiac patients (Cardiac-ICU), and neurological conditions (Neuro-ICU). ICUs can also differ based on the acuity level of patients (e.g., multi-system failure, single organ failure, step-down units for patients requiring close monitoring but not intensive medication or therapy).

Regardless of the specialty or specific acuity level, patients in ICUs require more attentive monitoring than patients in many other areas of a hospital. Thus, ICU nursing is a very demanding occupation. Unfortunately, hospitals are not always equipped with task supportive qualities such as effective soundscapes. This is concerning as studies have shown that demanding occupations (such as nursing) with poorly designed work environments can lead to high cognitive, physical, and emotional workload, negative health outcomes, and overall job dissatisfaction (Carayon et al. 1999; Ulrich et al. 2009; Aiken et al. 2002; Okcu et al. 2011). According to a national survey by the American Association of Critical-Care Nurses (AACN), a significant portion of U.S. nurses are not satisfied with their jobs, with more than 16 % indicating intentions to quite their job in the following twelve months and approximately 27 % in the next three years (Ulrich et al. 2009).

## Previous research on ICU acoustics

A growing body of research shows that hospitals (and ICUs in particular) are often very noisy. Beeping alarms, medical respirators, cleaning equipment, closing doors, footfall, staff and patients talking, and patient bodily sounds are just a few examples of the many noise sources found in ICUs. A landmark study by Busch-Vishniac et al. (2005) compiled historic data published on hospital noise between 1965 and 2005. The findings showed a clear trend towards rising sound levels over both day and night.

The impact of the high levels of ICU noise on nurses is concerning. Some previous research has examined the impact of the hospital soundscape on staff stress and annoyance, health outcomes, and work performance. For example, Morrison et al. (2003) found that higher average sound pressure levels were related to increased stress, annoyance, and heart rates among Pediatric-ICU staff. Improvements to the soundscape, such as adding sound absorption, have been correlated with improvement in staff perception of noise (MacLeod et al. 2007; Hsu et al. 2010) and the psychosocial environment (Blomkvist et al. 2005).

Studies relating noise and work performance are rare and offer conflicting results. Further, research specifically linking ICU nurse performance to the acoustic environment is essentially non-existent. There is some evidence that overall levels of operating room (OR) noise may decrease staff mental efficiency and short-term memory (Murthy et al. 1995) or x-ray reading performance (Park et al. 1994). However, a study by Moorthy et al. (2004) found no impact of OR noise on laparoscopic suturing performance of surgeons. Speech interference and increased medical errors are two additional, potentially dangerous effects of a poor sound environment; however, these effects have not been thoroughly investigated (Berglund et al. 1999; Busch-Vishniac et al. 2005). There is an urgent need for research in this area as one in four voluntarily reported medication errors involved confusion of drug names, with both spelling and sound similarity increasing the potential for false recognition errors (Lambert et al. 2001).

Although there is strong and growing evidence of the problematic soundscape in ICUs, few studies have linked rigorous analyses of the acoustic environment to the corresponding reactions of nurses. Many of the previous publications focus primarily on overall background noise levels and are lacking in other important detailed characteristics of the soundscape such as spectral content, time variance, reverberation, speech intelligibility, etc. The research described below pairs subjective perception evaluations with objective acoustic measurements to gain a more thorough grasp of how perceptual and physical acoustic parameters interact in the ICU.

## THREE CASE STUDIES

### Case Study I: Comparing nurse perception in two ICUs

Two ICUs with similar patient acuity but differing architecture were compared via objective acoustic measures and nurse questionnaires (Okcu et al. 2009, 2011). This paper highlights some of the key findings; additional details about the study methodology and results can be found in Okcu et al. (2009, 2011). The first unit was a relatively new, 20-bed, 2,229 $m^2$ Neurological ICU (Neuro-ICU). The second unit was an older, 20-bed, 1,161 $m^2$ Medical Surgical ICU (MedSurg-ICU). Both ICUs were located in the southeastern United States. Anectdotally, nurses in the MedSurg-ICU perceived the soundscape as quite problematic, whereas nurses in the Neuro-ICU were relatively satisfied. A detailed study was thus conducted to isolate the acutal perceptual and acoustical differences between the two units.

First, an electronic survey was administered to registered nurses working in both ICUs. Fifty-eight nurses responded. As shown in Figure 1, the noise in MedSurg-ICU was indeed perceived as significantly louder, more annoying, and having a greater negative impact on nurse work performance, health, and anxiety ($p<0.05$).

Interestingly, there was very little difference in the overall occupied sound levels measured in the two units, as shown in Figure 2. It was only through a more detailed analysis of the soundscape that differences between the two units began to emerge. Specifically, the “occurrence rate” showed that $L_{max}$ exceeded 80 dB 43 % of the time at the MedSurg-ICU nurse stations versus only 15 % of the time in the Neuro-ICU. Similar analyses for other occupied locations in the units (i.e., patient rooms, corridors) showed that the MedSurg-ICU was more "peaky" overall. The "occurrence rate" is a newer measure that analyzes the percentage of time that peak ($L_{peak}$) and maximum ($L_{max}$) noise levels exceed certain decibel levels (Kracht et al. 2007; Williams et al. 2007; Ryherd et al. 2008). A follow-up analysis showed that nurse perception of loudness and annoyance were significantly and positively correlated with the occurrence rate ($p<0.01$).

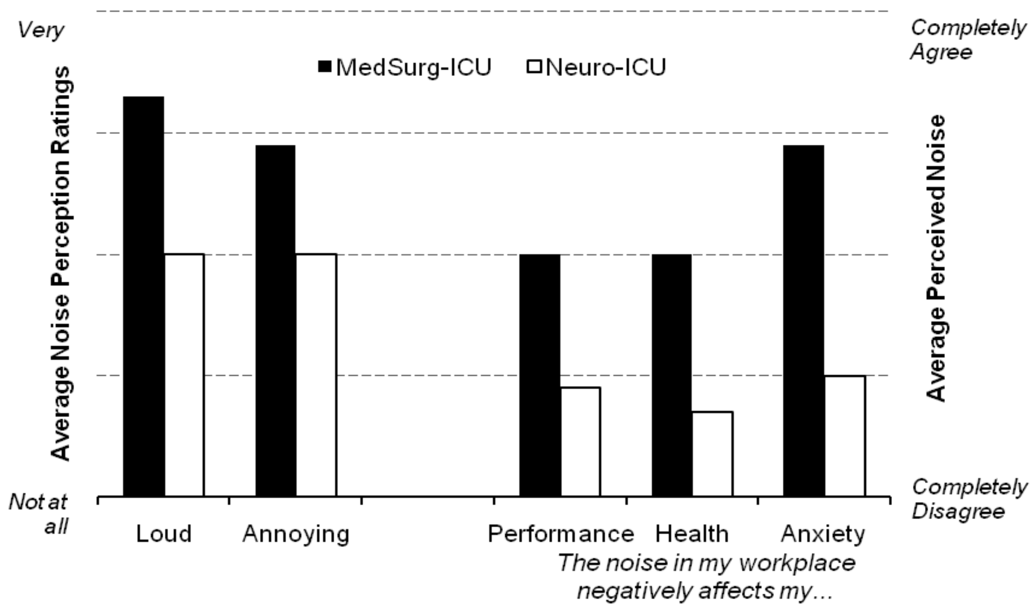


**Figure 1:** Nurse perception of loudness and annoyance + the impact of noise on nurse outcomes in the Case Study I ICUs (Reproduced from Ryherd et al. 2011 with permission)

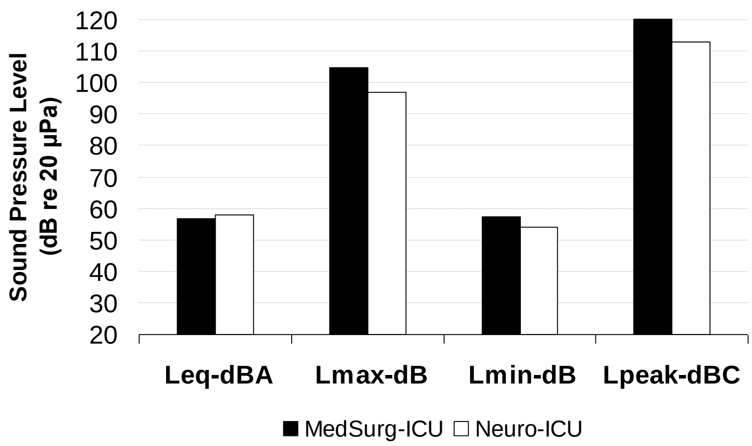


**Figure 2:** Measured A-weighted equivalent ($L_{eq}$), maximum, minimum ($L_{max}$, $L_{min}$) and C-weighted peak ($L_{peak}$) sound pressure levels measured in the Case Study I ICUs (Okcu et al. 2009)

## Case Study II: Auditory monitoring in ICUs

A second study looked more closely at the association between healthcare sound environments and specific caregiver tasks including auditory monitoring of patients. Previous research has shown that the majority of nurses' time (78 %) is spent on clinical nursing practice functions including patient monitoring (visual + auditory) and patient care activities (Hendrich et al. 2008). Monitoring patients requires nurses to be aware of a multitude of cues and have continuously alert minds, vigorous body states, and prompt and accurate decision-making skills (Carnevale 2009). Visual patient monitoring has been a key element of nursing practice since the late 19th century. Example visual cues that nurses are on alert for include changes in color or texture of the skin (e.g., rashes, bruising), assymetric chest movements, abnormal bleeding, etc. (Downes 2009). There is good evidence that improving visual cues in ICUs through design strategies such as reducing distances between caregiver work areas and patient rooms can improve patient safety (Joseph & Rashid 2007). In addition to utilizing visual cues, ICU nurses also rely on auditory cues as an eyes-free assessment technique when their hands and eyes are busy or there are obstacles blocking their views of patients. However, information regarding ICU monitoring of auditory cues is mainly limited to alarm recognition articles.

The authors are defining "auditory monitoring" as the process of hearing, interpreting, and responding to key auditory cues. The purpose of Case Study II was multifold and included determining to what degree nurses utilize auditory monitoring, identifying the key aural cues utilized in auditory monitoring, and understanding the role the ICU soundscape plays in the auditory monitoring process. An online survey was administered to registered nurses working in the Case Study I ICUs, as described above. As shown in Figure 3, the majority of nurses from the two ICUs agreed that both overall auditory and visual monitoring were crucial tasks. Further, individual sound tasks conducted as part of auditory monitoring (i.e., hearing, differentiating, and localizing auditory cues) were also perceived as crucial tasks.

Additionally, it was found that the main sounds that nurses listen for could generally be grouped into four categories: a) help calls (from patients or other caregivers); b) abnormal patient bodily sounds (e.g., choking, vomiting); c) safety threatening sounds (e.g., falls); d) alarms (e.g., patient monitors). The degree to which the overall soundscape impacts auditory monitoring is still under investigation.

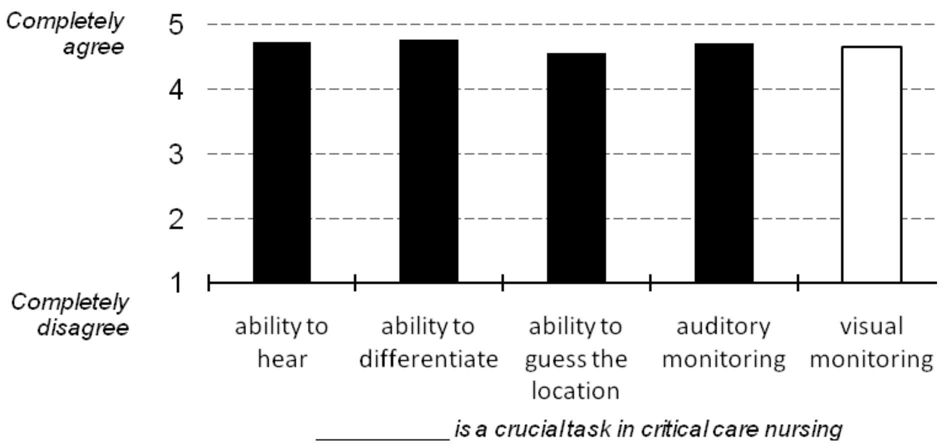


**Figure 3:** Perceived importance of three auditory tasks (ability to hear, differentiate, and guess location) in addition to overall auditory & visual monitoring in Case Study II (Okcu et al. 2009)

## Case Study III: General ICU nurse response

A third phase of the project examined general ICU nurse response with regards to occupation type and stress. This paper highlights a couple key findings from two relevant studies; additional details about the study methodologies and results can be found in Persson Waye et al. (2010) and Ryherd et al. (2008). Paper-based surveys were administered to nurses working in two ICUs in southern Sweden: a Neuro-ICU and a MedSurg-ICU. The Neuro-ICU survey consisted of demographic, noise perception, and noise-induced stress symptom questions. This survey was then expanded upon in the MedSurg-ICU study to consist of three primary sections: a) demographic, management climate, and social climate questions; b) physical environment and noise perception questions; c) health and noise-induced stress symptom questions. In total, 47 Neuro-ICU and 51 MedSurg-ICU nurses responded.

In the Neuro-ICU, 91 % of nurses surveyed thought that noise negatively affected them in their daily work environment. As shown in Figure 4, many nurses perceived noise as contributing to stress symptoms such as irritation (66 %), fatigue (66 %), problems concentrating (43 %), and tension headaches (40 %). The overall noise levels measured in this unit ranged between 53-58 dBA $L_{eq}$. Further, the occurrence rate showed that the Neuro-ICU sound environment was relatively peaky, as 90 % of the time $L_{max}$ levels exceeded 50 dBA and $L_{peak}$ levels exceeded 70 dBC.

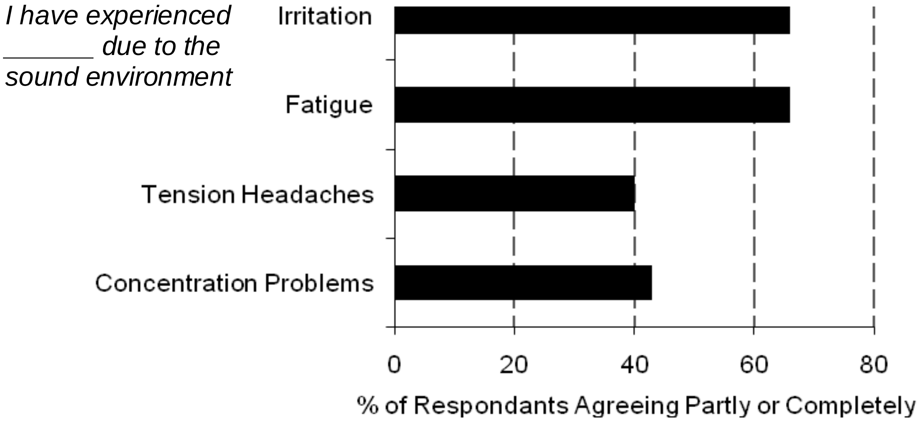


**Figure 4:** Nurse perception of the impact of noise on nurse outcomes in the Case Study III Neuro-ICU (Portions reproduced from Ryherd et al. 2008 with permission)

For the MedSurg-ICU study, results were compared to other personnel groups with similar distributions of gender, education, and age from non-ICU healthcare settings, offices, and pre-schools (Persson Waye et al. 2010). It was found that noise annoyance was significantly higher in the ICU setting compared to non-ICU healthcare settings and offices, but was significantly lower compared to pre-school teachers ($p<0.05$). The findings tracked with overall sound levels in these four types of spaces, as shown in Figure 5 below.

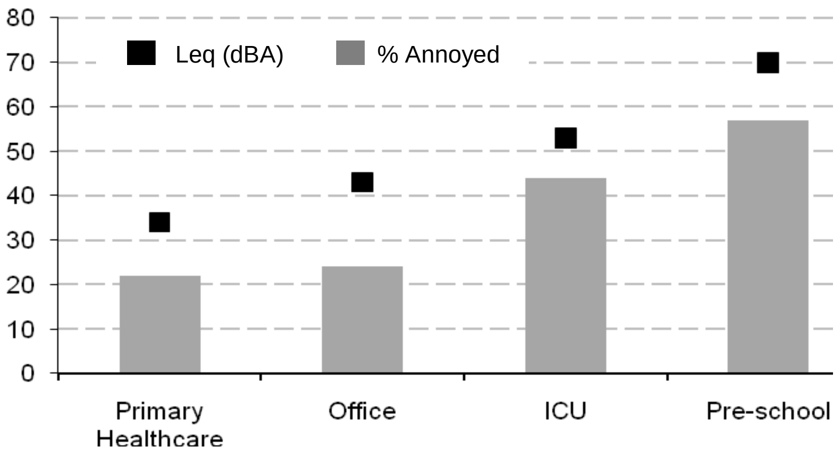


**Figure 5:** Prevalence of noise annoyance in the Case Study III MedSurg-ICU compared to other occupational groups (Reproduced from Persson Waye et al. 2010 with permission)

## CONCLUSIONS

Taken as a whole, the studies mentioned in this article provide new insight into the impact of hospital acoustics on nurses and potential steps to improve the sound environment. Some important findings highlighted in this article include the need for new metrics; for example, the occurrence rate appears to be a new metric that was well correlated with occupant response in Case Study I. This finding supports the concept that level descriptors alone (e.g. $L_{eq}$) are inadequate in describing the hospital soundscape and should be supplemented with fluctuation (e.g., occurrence rate), tonality, spectral quality, and other detailed noise descriptors. Further, it was clear in Case Study II that nurses rely heavily on auditory monitoring of cues such as help calls from patients and other care givers, abnormal bodily sounds, safety threatening sounds, and alarms. Maintaining the integrity of these critical auditory cues is critical to achieve a soundscape supportive of patient safety and staff performance. Finally, Case Study III demonstrated that many nurses feel noise negatively impacts them and may contribute to stress symptoms such as irritation, fatigue, tension headaches, and difficulty concentrating. The percent of annoyed nurses appears to be greater in ICUs than other non-ICU health settings and offices.

Ultimately, the value of this research lies in its potential impact, as such a large segment of the world's population would benefit from improved hospital soundscapes. In the US alone, approximately 6,000 ICUs care for 55,000 critically ill patients each day, and 4.7 million Americans work in hospitals (SCCM 2006, US Department of Labor 2010). HART aims to provide evidence to help support new guidelines and design standards by clarifying the relationships between the hospital soundscape and occupant response, identifying and evaluating new acoustic interventions, and transferring knowledge back to the engineering, architecture, and medical communities.

## ACKNOWLEDGMENTS

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# Consideration of objective measures of performance and subjective assessments under background speech in open-plan offices

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## SUMMARY

Short-term memory performance is important for activities in office environments and has effects on the efficiency of a company and employees' productivity. Negative effects of background speech on short-term memory performance have been shown in several laboratory studies (e.g. Banbury & Berry 1998). The Speech Transmission Index (STI) is considered to be a suitable physical set value to predict the decline of performance (Hongisto 2005).

However, the impact on subjective aspects such as perceived workload is rarely considered. It already has been shown that subjective assessment like disturbance and objectively measured performance do not necessarily match (e.g. Schlittmeier et al. 2008). Employees may be able to compensate for performance effects by an increase of effort but in turn perceived workload may increase (e.g. Yeh & Wickens 1988). In addition, a lack of perceived privacy, caused by background speech (among other factors) can influence mental workload and performance (e.g. Croon et al. 2005). This effect may not be immediately visible, but must be considered in the long term with respect to a decline of job dissatisfaction, which can cause absenteeism and even job termination. To avoid these consequences an exclusive focus on the loss of performance is not sufficient.

Therefore the reported results consider both the effects of background speech varying in intelligibility (STI) to objective and subjective measures. It is shown that subjective assessments, e.g. of workload, disturbance, territoriality as well as privacy and objective measures of performance correlate with the STI.

## INTRODUCTION

Physical characteristics of an office environment have effects on behavior, perception and productivity of workers (Crouch & Nimran 1989; Sundstrom et al. 1980). In open-plan offices several workstations are located in one spacious room and may be separated by internal boundaries like screens or shelves, while conventional workplace environments provide closed, private offices for employees. In open-plan offices, increased disturbances and distractions, an increased feeling of crowding and a loss of privacy may be the consequence (Crouch & Nimran 1989; Maher & von Hippel 2005).

Several studies demonstrated the relation between office noise and impaired cognitive performance (Banbury & Berry 1998), noise and decreased job satisfaction, lower motivation, higher perceived workload (Smith-Jackson & Klein 2009) stress and lower productivity (Sundstrom et al. 1994). Another issue of open-plan offices is the lower perceived privacy (Sundstrom et al. 1980, 1982; Crouch & Nimram 1989; Oldham & Brass 1979). One type of privacy is speech privacy which means the ability to have a conversation inside the workspace without being overheard and understood by people outside it (Sundstrom et al. 1986).

Irrelevant speech is the most disturbing noise, more than other types of office noise like telephone ringing and copiers. Schlittmeier et al. (2008) have proven that poorly intelligible speech has a significant lower impact on the disturbance of verbal short-term memory and mental arithmetic than highly intelligible speech. Background speech has no effect on verbal-logical reasoning performance. However, in all conditions, subjective disturbance ratings are similar, for example, poorly intelligible speech is rated as the least disturbing speech condition but still disturbing in comparison to silence. This shows that subjective assessment and objectively measured performance do not necessarily match.

To evaluate the impact of background speech of varying intelligibility the Speech Transmissions Index (STI) is used. The STI is a physical measure of speech intelligibility. It varies from 0 (completely unintelligible) to 1 (perfect intelligibility).

The model of Hongisto (2005) describes the relation of work performance and the STI. With increasing speech intelligibility (STI > 0.70) cognitive performance decreases. If the STI is low (STI < 0.20) the optimum performance is predicted. A linear relationship between STI and performance is assumed between STI values 0.20 and 0.70. Liebl et al. (2010) proved a strong relationship between cognitive performance (Serial Recall Task) and STI.

The goal of the present study was to examine the relationship between subjective assessments and the STI, which was systematically varied from 0.13 to 0.61, compared to the results found by Liebl et al. (2010). It is possible to describe acoustic environments in a more comprehensive way by considering both, objective performance and subjective comfort.

## METHOD

### Participants

A sample of 24 participants from German speakers was selected. They were aged 20 to 50 years (Md = 23 years) and reported normal hearing. A small allowance was paid for participation.

### Procedure

The design of the experiment was one-factorial with repeated measurement. The experiment was placed in a laboratory and presented by an Apple MacBook with the experimental software PsyScopeX. The experimental task (Serial Recall Task, see Liebl et al. 2010) was followed by the subjective ratings. After having processed the performance task, subjective ratings (perceived annoyance, perceived ability to concentrate and perceived difficulty) were evaluated. A dichotomous answer should be given to the question of privacy (request of increased distance to the sound source). The participants also estimated the perceived distance to the sound source in meters. Sounds were played via headphones (Sennheiser HD 600) using a CD-Player (Sony CDP-103) and an amplifier (AKAI AM-49). Over all participants the sequence of the experimental conditions was balanced. The duration of the experiment was approximately 2.5 hours.

### Sound scenarios

A room of 64 $m^2$ with standard workstations was used as an office mockup (Figure 1). Between adjacent workstations either no screens, absorptive (h = 1.70 m) or reflective screens (h = 1.70 m) were placed. The floor was carpeted and the ceiling absorptive (NRC = 0.70). At position 1 the sounds were played with a dodecahedron (h = 1.20 m) and were recorded by an artificial head (h = 1.20 m) at positions 2, 3 and 7.

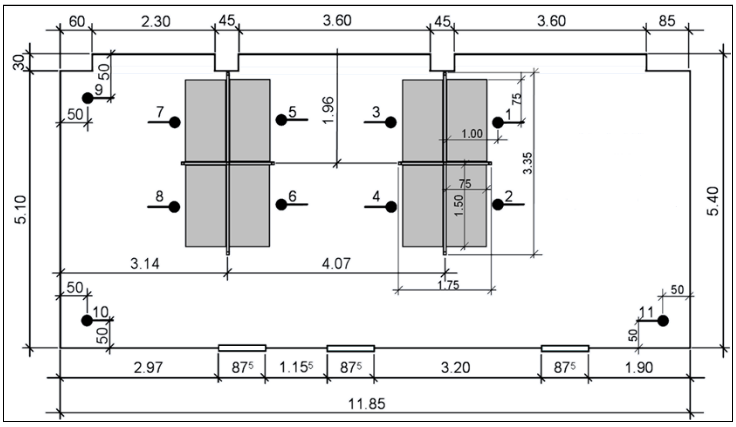


**Figure 1:** Sketch of the office mockup depicting the arrangement of workstations. Numbers 1 to 8 represent individual workplaces. Sound was played at position 1 and recorded at positions 2, 3 and 7.

An ANSI-specified speech spectrum with normal vocal effort was used to calculate the STI. With low level background noise the absorptive and reflective screens were not sufficient to create a broad range of STI values since the STI values at positions 2, 3 and 7 were very similar. By adding noise (39 dBA) and adapting the speech level, twelve sound scenarios with STI values from 0.13 to 0.61 were generated which were used in the experiment.

RESULTS

The strong relationship between STI values and cognitive performance was proved by Liebl et al. (2010). The empirical data fit the model of Hongisto (2005), more errors were made with increasing STI.

Subjective ratings of the different sound scenarios also proved to correlate with the STI. Perceived annoyance significantly correlates with the STI values ($r = 0.959$, $p<0.01$). The higher the STI values, the higher the ratings of perceived annoyance (Figure 2).

Figure 3 shows the correlation between the estimated distance to the sound source and the STI. The higher the STI, the lower the distance is estimated ($r = -0.940$, $p<0.01$).

Figure 4 shows the violation of privacy (request of increased distance) as a function of STI values. If the STI is high, more participants intend to increase the distance to the sound source. The estimated distance to the sound source significantly correlates with the percentage of violation of privacy (request of increased distance) ($r = -0.850$, $p<0.01$) (Figure 5).

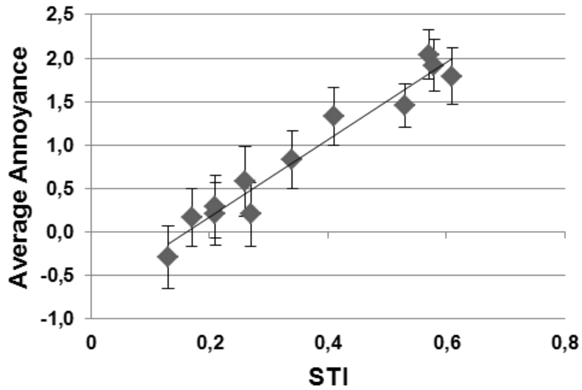


**Figure 2:** Average perceived annoyance as a function of speech intelligibility (STI)

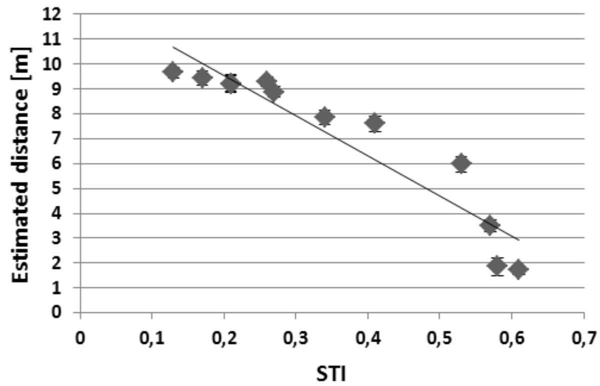


**Figure 3:** Estimated distance to sound source as function of speech intelligibility (STI)

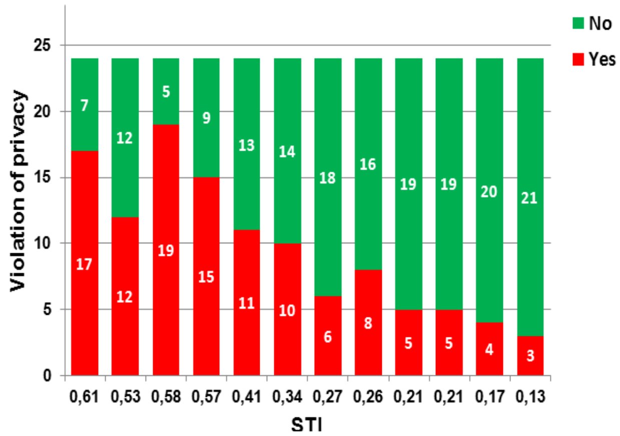


**Figure 4:** Violation of privacy as a function of speech intelligibility (STI)

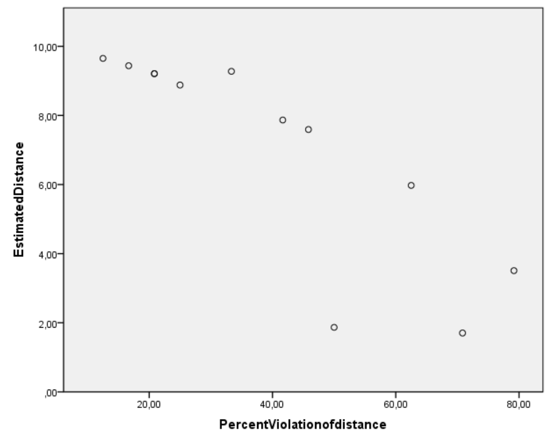


**Figure 5:** Estimated distance as a function of percentage of violation of privacy

## CONCLUSIONS

The results show a high correlation of subjective assessments with the STI value. Objective performance also highly correlates with the STI (Liebl et al. 2010). Speech intelligibility seems to be a good predictor of perceived acoustic comfort in open-plan offices. Higher STI values have a negative impact on the perceived assessments.

Estimated distance to the sound source correlates with the STI. But this relation can be a function of the method of calculation of the STI. In this experiment the STI was calculated by changing the signal-to-noise-ratio by keeping the same level of noise and decreasing level of speech signals. Because of the decreasing level of speech signals it is possible that the distance to the sound source was estimated farther. The lower a speech signal, the further away a sound source is positioned. In this case, privacy is not only related to speech intelligibility but also to the level. Probably the level is more relevant for perceived privacy. To generate the STI in another way – same level of speech and increasing noise – can be a possibility to get more information on the relation between STI, perceived distance and lack of privacy. Further investigations with regard to the level of signals would be very useful.

It is possible that another problem with the STI is the speech spectrum. An ANSI speech spectrum was used to create the STIs, but no other voices were used. In further questions male and female voices can be used for the creation of the STI.

In this study perceived privacy is rated by the request to increase the distance to the sound source only. For a more comprehensive approach it is advisable to evaluate privacy in a combined way using questionnaires, developed e.g. by Crouch & Nimran (1989) or a behavior-based questionnaire, together with ratings of the estimated distance to the sound source and further assessments.

In this study objective performance and subjective assessments both show an increasing disturbance with increasing STI. Therefore, it is recommended to consider both, objective measurements and subjective assessments in future investigations.

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# Memory of spoken discourse masked by speech

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## INTRODUCTION

When we listen to a talker in optimal conditions we can follow what is said on the basis of bottom-up processes mapping the speech automatically onto our mental lexicon. However, when the speech signal is distorted, as when the target speech is masked by another voice, the speech segments no longer match the phonological representations in long-term memory and top-down working memory processes must be engaged to interpret what is said (Rönnberg 2003; 2008; 2010). Since the capacity of working memory varies inter-individually, people with high working memory capacity (WMC) should be better able to process and subsequently remember the message in the target signal. However, thus far no research has addressed how WMC modulates the effect of a to-be-ignored speech signal on auditory-verbal memory processes. In contrast, the role of WMC in susceptibility to the effects of irrelevant speech on visual-verbal memory processes is well explored (Sörqvist 2010). Furthermore, in the context of dichotic listening, high-WMC individuals are better able to ignore a speech stream presented to the to-be-ignored ear (Conway et al. 2001) and better able to divide attention across both ears (Colflesh & Conway 2007). Based on this literature, WMC should modulate the disruption of episodic long-term memory of materials conveyed by a speech signal that is masked by another speech signal. The primary purpose of the present study was to investigate the role of WMC to episodic long-term memory of spoken materials in a cocktail party context. Moreover, we intended to test which of two complex-span tasks (i.e., reading span and size-comparison span, typical tasks that measure WMC) is the better predictor of the effect.

## METHOD

### Participants

A total of 44 students (*M* = 25.91 years, *SD* = 6.51) at the University of Gävle participated in this experiment. They all reported normal hearing and normal or corrected-to-normal vision, and they received a small honorarium as compensation for their participation.

### Materials

The reading span (RSPAN) task was adopted from Daneman and Carpenter (1980) and the size-comparison span (SICSPAN) task was adopted from Sörqvist et al. (2010). In RSPAN, the participants read sentences and determine whether they are normal (e.g., the boy ate a sandwich) or absurd (e.g., the banana ate an apple). After reading a set of sentences, the participants were probed to recall the first (e.g., boy banana) or the last (e.g., sandwich apple) words presented in each sentence. The number of words recalled is used as a measure of WMC. In SICSPAN, the participants switched between comparing the size of objects (e.g., "Is ELEPHANT smaller than MOUSE?") and encoding words (e.g., LION) for later recall. After a set of words, the participants were asked to recall the to-be-recalled words and to avoid recalling words from the distractor activity. All words within a set (i.e., to-be-recalled words and comparison words) belong to the same semantic category (e.g., Animals). This enhances item confusion and makes selective retrieval of the to-be-recalled items (and selective encoding of the to-be-recalled items into the memory-set) difficult. Two stories were used to measure episodic long-term memory. One story was about a fictitious culture called the "Timads" and the other was about a fictitious culture called the "Lobiks". Both stories consisted of 10 short paragraphs about different topics and each story was approximately 7.5 minutes long. The participants listened to the stories and afterwards they answered 20 questions about each story respectively. To create a masking speech sound, a third story about a fictitious culture called the "Ansarians" was recorded, but spoken by a different male. The masking speech was spectrally inverted around 2 kHz to create rotated speech. All sound stimuli were presented binaurally through headphones. The target speech was presented at approximately 60 dB(A) $L_{eq}$ and the masking speech (normal or rotated) was presented at approximately 55 dB(A) $L_{eq}$. To obtain a measure of how well the participants could hear what was said in the two listening conditions (normal and rotated masking speech), the participants also performed a hearing test. Twelve sentences from the two stories used in the episodic long-term memory test (6 from the Timads and 6 from the Lobiks) were used as target materials for the hearing test.

## Design and Procedure

A within-participants design was used. The participants completed the tasks in three consecutive blocks; first, the reading span task and the size-comparison span task; second, the hearing test; and third, the two episodic long-term memory tasks. All tasks and sound conditions were counterbalanced between participants.

**Table 1:** Mean scores (in percentage) on the hearing test and the episodic long-term memory (LTM) test in two listening conditions (normal vs. rotated masking speech)

| | Masking sound | | | | | | |
|---|---|---|---|---|---|---|---|
| | Normal speech | | Rotated speech | | Difference | | |
| Test | *M* | *SD* | *M* | *SD* | *M* | *SD* | *t* |
| Hearing | .85 | .15 | .99 | .04 | .14 | .14 | 6.69** |
| Episodic LTM | .18 | .13 | .28 | .17 | .10 | .13 | 4.93** |

Note: the *t*-tests are based on a within-participants design with 44 participants

** $p<0.01$

**Table 2:** Hierarchal regression analyses of the relation of size-comparison span and reading span to the effects of masking speech on episodic long-term memory

| | Relation to episodic long-term memory disruption | | |
|---|---|---|---|
| Variable | β[a] | $t$ | $\Delta R^2$ |
| Predictors entered alone | | | |
| Size-comparison span | .37 | 3.68** | .14 |
| Reading span | .25 | 2.21* | .06 |
| Predictors entered simultaneously | | | |
| Size-comparison span | .34 | 2.83** | .08 |
| Reading span | .08 | 0.63 | < .01 |

* $p$<0.05; ** $p$<0.01

[a] Standardized regression coefficient for predictors of episodic long-term memory in the normal speech condition after control for episodic long-term memory in the rotated speech condition and hearing in the normal speech condition

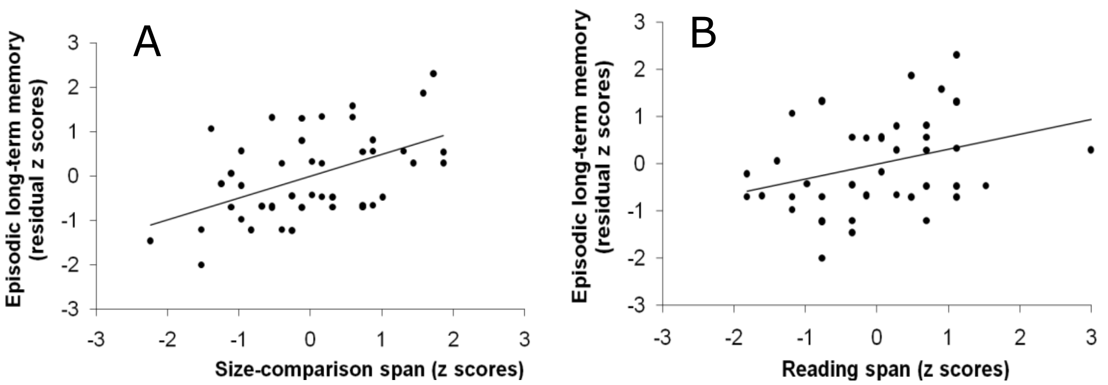


**Figure 1:** The figure illustrates the relationship between working memory capacity (Panel A: size-comparison span; Panel B: reading span) and episodic long-term memory for spoken discourse masked by speech (when variance explained by episodic long-term memory in the rotated-speech condition and hearing in the normal speech condition is statistically removed).

## RESULTS

As can be seen in Table 1, performance on both the hearing test and the episodic long-term memory test was significantly impaired when a normal speech masked the target speech. This study intended to test if working memory capacity (WMC) modulates the effects of masking speech on episodic long-term memory of materials conveyed by a target speech signal. Moreover, we intended to test if SICSPAN is a stronger predictor of this relationship than RSPAN is. To this end, we used a series of residual analyses in the context of hierarchical regression analysis (cf. Sörqvist et al. 2010). The results are reported in Table 2 and Figure 1. Both WMC tasks predicted the effect significantly, but size-comparison span is the stronger predictor of the two.

## DISCUSSION

The present study demonstrates an important role for cognitive-control processes in listening. Specifically, individual differences in WMC appear to underlie individual differences in susceptibility to the effects of to-be-ignored speech on auditory-verbal memory processes, consistent with previous investigations on cross-modal auditory distraction (Sörqvist 2010). This is particularly noteworthy because it suggests that individual differences in susceptibility to within-modal and cross-modal auditory distraction are mediated by the same top-down cognitive processes. Of particular interest here, size-comparison span (SICSPAN) appears to be a stronger predictor of the magnitude of this effect than reading span (RSPAN). When the participants perform SICSPAN they must recruit inhibitory processes to resolve semantic confusion (or competition taking place between category exemplars at encoding and at retrieval of target items) in contrast to RSPAN that does not require resolution of semantic confusion. This may be the reason why SICSPAN is the stronger predictor.

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# Restoration at work: effects of different sound exposures

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## INTRODUCTION

Open-plan offices are increasingly more common as work-environments for employees. There are, however, concerns about the effects of noise on cognitive performance and health in these office-designs (see reviews by Navai & Veitch 2003; Oommen et al. 2008; Rashid & Zimring 2008). There are also studies indicating that noise (such as irrelevant speech) decreases performance (e.g. Haka et al. 2009; Schlittmeier et al. 2008; Sörqvist et al. 2009), and enhance stress (Evans & Johnson 2000).

There are good reasons to expect that the impacts of noise in an open-plan office vary not only with the types of noise and the layout of the office, but also with characteristics of persons exposed to noise. One such variable is their degree of hearing impairment. In Sweden more than 10 % of the population has some hearing impairment and among them more than half are in working age (HRF 2008). However, no studies to the author´s knowledge, have systematically addressed how hearing impaired persons' cognition is affected by open-plan office noise.

If office noise has a negative effect on both hearing impaired and normal hearing persons, one important task is to find ways to attenuate the negative outcomes. However, research on restorative environments has so far paid little attention to how environmental sounds might affect restorative processes (Alvarsson et al. 2010). Studies of restoration have mainly shown that nature environments are restorative to be in or to look at when cognitively fatigued (e.g. Berto 2005; Hartig et al. 1996). These studies focused on the *visual* perception of the environment and not on the *sound* conditions per se. There are, however, some results indicating faster and more complete restoration (according to both performance and physiological measures) for participants exposed to nature movies with environmental sounds, in comparison to those exposed to other environments including sounds (Laumann et al. 2001, 2003; Ulrich et al. 1991). Some studies have also shown a restorative advantage of natural versus urban settings in field conditions that included the sounds typical of each type of environment (Berman et al. 2008; Hartig et al. 1991, 2003).

Khalfa et al. (2003) have also shown the restorative effects of positive sounds only. They compared recovery from sitting in silence with listening to soft music, and found that music promoted faster decline in salivary cortisol, measured after 15 minutes into the relaxation period. However, no studies (to the author’s knowledge) have investigated whether positive nature sounds by themselves can promote restoration and ensuing cognitive performance.

The aim of our first study (A) was to investigate how noise in open-plan offices affects cognitive performance and acute stress, and whether it is possible to promote cognitive restoration with exposure to pleasant sounds and film-clips of pleasant nature environments (during a 7 minutes break) after having been exposed to aversive sounds. I.e. we hypothesized more precisely the following expected order of restorativeness: a nature movie with nature sounds (positive stimuli for two senses), just nature sounds (positive stimuli for one sense), silence (no stimuli) and noise (negative stimuli).

In the second study (B) we also examined whether these effects differ between hearing impaired and normal hearing persons and investigated the restorative effects of a longer (14 minutes) break.

Due to lack of space, only the effects of the restorative break on performance and stress will be presented here (i.e. not the effects of noise during the work period).

METHODS – EXPERIMENT A

### Design and participants

We designed an experiment with two acoustic environments (low noise, high noise) varied within subjects and four restorative conditions (nature movie, nature sound, silence, noise) manipulated between subjects.

The participants were 47 normal hearing and normal seeing persons recruited from the University of Gävle (27 female; mean age = 26). Participants were randomly assigned to conditions and participation in all the three sessions was compensated with 990 Swedish crowns.

### Research setting and noise conditions

The research was carried out in an office laboratory (63 $m^2$) at the University of Gävle. The eight workstations were separated with 1.43 meters high screens and each cubicle was 1.24 meters wide.

The noise used in the experiment was recorded in four positions in a real open-plan office in Sweden. From the multi-channel recordings one hour of office noise was extracted and edited and reproduced in the test room by eight loudspeakers, two at each wall, and one subwoofer. Two noise conditions were designed, one with high- and one with low noise level. In the high noise condition, additional phone and sound signals were added to the office noise. The noise was reproduced with an equivalent A-weighted sound pressure level ($L_{Aeq}$) of 51 dBA in the room. In the low noise condition the office noise, including the additional phone and sound signals, was low pass filtered which reduced $L_{Aeq}$ in the room by 12 dBA to 39 dBA.

### Restoration conditions

After two hours of work in office noise the participants went through a restoration period for seven minutes at their desk with headphones on. There were four different restorative conditions: see movie clips of rivers and hear river sounds, listen to the river sounds without movie clips, sit in silence, or continue to listen to the office noise from the high noise condition.

### Measures

We used several different cognitive tasks to measure the effects of noise and cognitive fatigue/restoration (see Figure 1 for an overview of the tasks and their order). Perceived tiredness and motivation were measured with a questionnaire (SOFI) developed by Åhsberg et al. (1995). The measures of the participants stress hormone levels were obtained through urine (catecholamines) and saliva (cortisol) samples. All measures used in Experiment A are further described in Jahncke et al. (2011a, b).

| **Section 1** | **Premeasures and Relaxation** | | | | **Noise treatment** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Urine sample | Saliva sample | Relax | Saliva sample | SOFI [a] | Cognitive tasks [b] | Filler tasks [c] | Cognitive tasks [d] | Saliva sample | SOFI | Filler tasks |
| **Section 2** | **Restoration treatment** | **After measures** | | | | | | | | | |
| | Movie, River sound, Silence, or Noise | Saliva sample | SOFI | Cognitive tasks [d] | Saliva sample | Urine sample | | | | | |

Time →

[a] Swedish Occupational Fatigue Inventory. [b] The order of the cognitive tasks was as follows: Sustained Attention to Response Test (SART), Proactive interference (PI), Flanker, Reading span, Serial recall – letters, Updating, Operation span, Logical problems, Reading comprehension, Serial recall – numbers, Shifting. It took circa 110 min to complete the tasks. [c] The filler tasks were included to make all participants begin the next phase at the same time.[d] The order of the cognitive tasks at *Postwork* and *Postrest* was as follows: Sustained Attention to Response Test (SART), Proactive interference (PI). It took about 10 min to complete these tasks.

**Figure 1:** Overview of the procedure for one experimental session

## Procedure

Data collection took place at a simulated office at the University of Gävle, Tuesdays and Wednesdays between two and five p.m. Before the two experimental sessions, participants went through a practice session for one hour, several days in advance, to help reduce possible training effects on the cognitive tasks. The experimental session procedure is presented in Figure 1. The whole procedure took about three hours to complete and seven to eight participants were tested at each occasion.

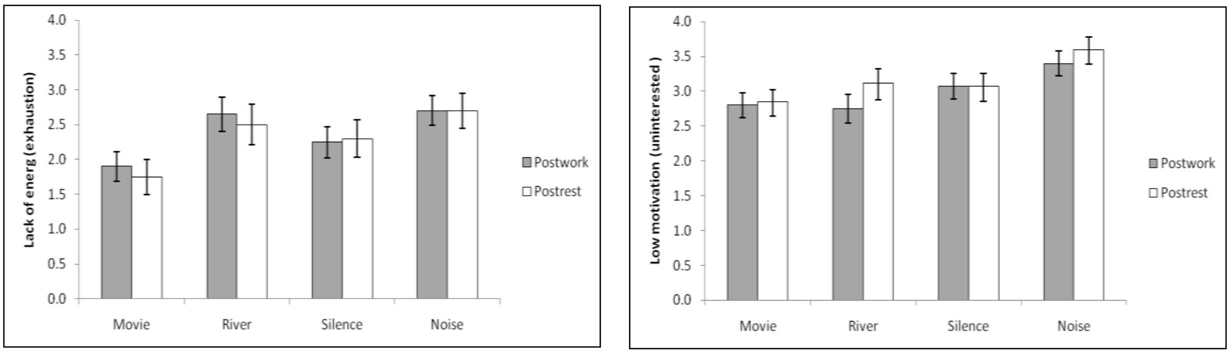
## Statistical analyses

A General linear model with repeated measures (mixed) design was used for the analysis of fatigue and restoration effects. When Mauchly's test indicated non-sphericity in the variance-covariance matrix for the within-subject analyses the Greenhouse-Geisser adjusted degrees of freedom and resulting *F*-tests are reported.

# RESULTS – EXPERIMENT A

## Effects of restoration on self ratings of fatigue

When comparing the self-rating scores (SOFI) from Postwork (before the restoration period) to Postrest (after restoration), the analysis revealed a significant between-subjects effect of restorative conditions on change in the ratings of lack of energy (exhaustion), $F(3, 29) = 3.10$, $p<0.05$, *partial* $\eta^2 = 0.24$; and of lack of motivation (uninterested) $F(3, 29) = 3.02$, $p<0.05$, *partial* $\eta^2 = 0.24$. Decomposition of this effect using simple effects analysis (LSD) demonstrated that the participants who saw the movie (including river sounds) rated themselves as *having more energy* (i.e., were less exhausted) in comparison with the participants listening to noise ($p<0.01$) and those listening to river sounds ($p<0.05$). The participants who listened to noise during the restoration period rated themselves as being *less motivated* (i.e., more uninterested) in comparison with the participants who listened to river sounds ($p<0.05$) or saw the movie ($p<0.01$), see Figure 2a and b. The post hoc analysis also demonstrated a marginal difference in *tiredness* (yawning) between the movie condition and the noise condition ($p=0.055$) and between the movie and river sound conditions ($p=0.052$). The results further indicated that the participants who heard river sounds or office noise during the restoration period rated their overall experience more negatively than the participants in the other two restoration conditions. These results support our main hypothesis by indicating that the sound conditions may promote different restorative experiences. No statistically significant effects from the restoration period were detected on the cognitive or physiological measures (all *Fs*<1).




Note: The scales ranged from 1 = not at all to 4 = a lot.

**Figure 2:** Self-ratings of **(a)** lack of energy (exhaustion) **(b)** low motivation (uninterested) before and after 7 minutes of rest in each restorative condition. Error bars are the standard errors of the mean.

## METHODS – EXPERIMENT B

The research setting, procedure and design were the same in Experiment B as in Experiment A, except the inclusion of hearing status (hearing impaired, normal hearing) as between-subjects factors and that one more urine sample was added in the middle of the session. The measures used in Experiment B are further described in Jahncke et al. (2011a, b).

### Participants

The participants who took part in the study consisted of 20 hearing impaired (female 9; median age = 53) and 18 normal hearing persons (female 8; median age = 48). The participants with hearing impairment were recruited from the Swedish association of hard of hearing people (HRF) and we only included those in the age span 20-65 years old (some participants were however retired), and excluded those who reported having severe tinnitus and/or Menières disease.

### Noise and restoration conditions

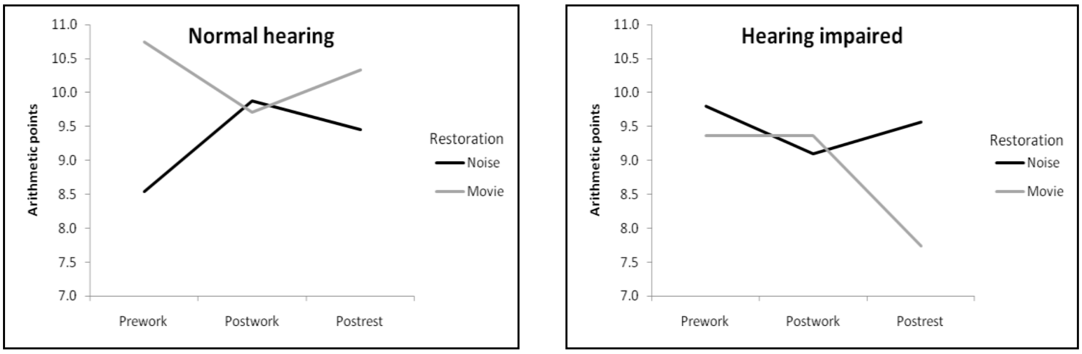
The same noise was reproduced as in Experiment A, however, now with a higher/lower equivalent A-weighted sound level (60 $L_{Aeq}$ vs. 30 $L_{Aeq}$) in the room.

The participants also went through a longer restoration period in Experiment B (14 minutes) compared to Experiment A (7 minutes). Only two restorative conditions were included this time in *the high noise condition*: half of the participants saw a movie with clips of nature environments in quiet and half of the participants just listened to office noise. In *the low noise condition* all participants sat in quiet during the restorative period (included as a control condition).

## RESULTS – EXPERIMENT B

### Effects of restoration on cognitive performance

As a first step we analyzed arithmetic performance over time during both the low noise exposure condition - with quiet as restorative condition, and the high noise exposure condition - with movie and noise as restorative condition. The analysis with session order and hearing (2x2) as between subjects factors, and noise and time (2x3) as within-subjects factors revealed a significant interaction between noise x time x hearing, $F(2, 58) = 3.12$, $p<0.05$, *partial* $\eta^2 = 0.10$. Both the normal hearing and hearing impaired participants had declined performance from Prework to Postwork in both noise conditions. Thereafter the hearing impaired participants´ performance increased to Prerest after a break in quiet and decreased after a break with movie or noise. For the normal hearing the opposite pattern emerged with decreased performance after restoration in quiet and increased performance after restoration with movie or noise (see Figure 3a and b).




Note: The scales ranged from 0 – 16 pts of correct answers.

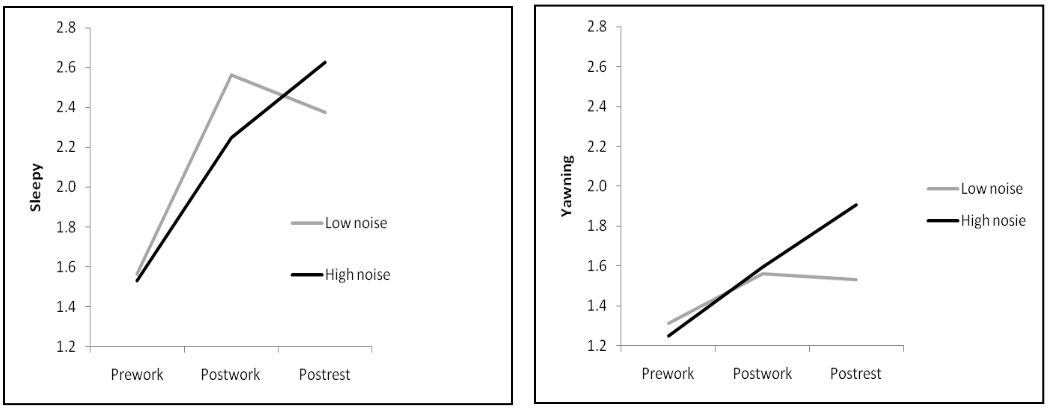
**Figure 3:** Arithmetic performance (points) for **(a)** the normal hearing and **(b)** the hearing impaired in high noise, with restoration during noise or with nature movie

As a second step we analyzed performance in the high noise condition only, to further explore the effects over time with restoration in noise or with a movie. The analysis with restorative condition, hearing and session order (2x2x2) as between-subjects factors and time (3) as within-subjects factor revealed a significant interaction between time x restoration x hearing on arithmetic performance (points), $F(2, 50) = 3.63$, $p<0.05$, *partial* $\eta^2 = 0.13$. Following our hypothesis, the normal hearing participants who had noise during their restoration period had declined performance from Postwork to Postrest and those who watched the nature movie had improved performance over the same time points. However, the hearing impaired showed the opposite pattern. A further analysis to check that the interaction derives from the change from Postwork to Postrest (and not from Prework to Postwork) showed that the interaction between time x restoration x hearing was still significant when only considering performance before and after the restoration period, $F(1, 25) = 7.50$, $p< 0.01$, *partial* $\eta^2 = 0.23$. An analysis conducted on the normal hearing only revealed a tendency of interaction between Time x Restoration, $F(2, 26)$ =, $p = 0.076$, *partial* $\eta^2 = 0.18$, indicating that the effect of restoration tend to be prominent even if hearing is not considered. According to arithmetic performance our hypothesis of restoration seems to hold for normal hearing only.

The analysis of the other performance task (Sustained attention to response task; SART) revealed no effects of the restorative conditions (*F*s<1). The participants had few errors in this task which might indicate a ceiling effect.

## Effects of restoration on self ratings of fatigue

The analysis with hearing and session order (2x2) as between-subjects factors and noise and time (2x3) as within-subjects factor revealed an interaction between time x noise on the amount of yawning, $F(2, 48) = 3.92$, $p<0.05$, *partial* $\eta^2 = 0.14$; and a tendency to an interaction on sleepiness, $F(2.48) = 2.80$, $p=0.07$, *partial* $\eta^2 = 0.10$. The feelings of fatigue first increased from Prework to Postwork in both noise exposure conditions. Thereafter it was a decrease of fatigue to Postrest in the low noise condition (with restoration in quiet). The decrease of fatigue in quiet follows our hypothesis. However, in the high noise condition it was an increase of fatigue to Postrest, with the two restorative conditions of noise and nature movie considered as one restorative condition (see Figure 4a and b). A further analysis of only the restorative conditions in the high noise condition (i.e. movie vs. noise) did not reveal any significant effects *(F*s<1). Accordingly, no support was found for a nature movie to be more restorative than continued noise exposure in the subjective ratings. Though, after low noise exposure the silent condition promoted restoration in an efficient way.




Note: The scales ranged from 1 = not at all to 4 = a lot. Restorative conditions: Low noise = quiet, High noise = nature movie or noise

**Figure 4:** Self-ratings of **(a)** yawning and **(b)** sleepiness at Prework, Postwork and Postrest in high and low noise

The analyses of self ratings of motivation with hearing and session order (2x2) as between subjects factors noise and time (2x3) as within-subjects factors, revealed a significant interaction between time x noise x hearing on motivation (passiveness), $F$ $(2, 48) = 3.04$, $p = 0.057$, *partial* $\eta^2 = 0.11$. Motivation decreased over time in both noise exposure conditions (i.e. high- and low noise), for the both hearing groups. Thereafter motivation decreased more for the normal hearing participants when they were in the low noise exposure condition (with restoration in quiet), compared to the high noise exposure condition (with restoration in noise or movie; i.e. in this analysis seen as one condition). The opposite pattern emerged, however, for the hearing impaired. Their motivation decreased more during restoration with noise and movie, compared to restoration in quiet. A further analysis of the restorative conditions in the high noise exposure condition only (i.e. movie vs. noise) did not reveal any significant effects (*F*s<1).

**Effects of restoration on acute stress**

No effect of restoration was found on the urinary catecholamines and salivary cortisol (All *F*s<1).

## CONCLUSION

So far, many environments have just been studied according to their visual value for restoration. The present study starts to address the gap in knowledge concerning the effects of the aural environment on the depletion and restoration of adaptive resources. The results from Experiment A showed that the participants who saw a nature movie (including river sounds) during the seven minutes break, rated themselves as having more energy after the restoration period, in comparison with both the participants who listened to noise and river sounds. Remaining in office noise during the restoration phase also affected motivation more negatively, than listening to river sounds or watching the nature movie. The stress hormones and cognitive performance were, however, not affected by the restorative conditions.

The results from Experiment B showed that a quiet break for 14 minutes was the most beneficial for the hearing impaired participants´ performance after noise exposure, while a break with other stimuli (nature movie) was most beneficial for the performance of the normal hearing persons. The normal hearing individuals also showed declined performance after a break with office noise. However, the quiet condition was the only condition which reduced self-rated fatigue for both hearing status groups.

This kind of multi-modal restoration also needs to be addressed in a larger context than at work. Looking at a combination of senses might indicate that a nature environment such as a noisy park might restrict restoration while a quiet park environment, where only nature sounds are heard, might promote restoration. When comparing different environments, it might also turn out that a calm café with soft music in a noisy urban environment might be more restorative than going to a crowded and noisy park, which would contrast with earlier results. The noise-level increments at workplaces and in urban areas demand compensatory strategies that include access to restorative environments. These are health issues that need to be further addressed.

## ACKNOWLEDGEMENTS

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# Background noise means process interference in counting performance

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ABSTRACT

The present paper examined the effects of different background sounds on counting performance. Two experiments were carried out to test how counting performance was affected by four background noise conditions: spoken numbers, numbers played backwards, names of occupations and a silent control condition. The hypothesis was that the condition with spoken number noise should have strongest negative effect on counting performance. The results from Experiment 1 gave no support for the hypothesis, since no significant difference between conditions was found. Experiment 2 used a more complex counting task and a faster presentation rate of the background sounds. The condition with spoken number noise showed largest effect on counting performance, and performance in the control condition was better than all background sound conditions. The results are in line with the theory of *interference by process.*

Keywords: Noise, Counting, Interference by process.

## INTRODUCTION

What kind of background sound is most disruptive for counting processing, and thereby affects mathematical performance? In order to find optimal learning conditions in schools, we need information about the cognitive nature of distraction. If the overall noise level is the main issue for disruption, we should minimize the number of noise sources and mount a big amount of absorbing panels. But if irrelevant speech affects performance perhaps classrooms with smaller cells could be a more effective solution. Thus, to design a classroom with acoustic characteristics that offers good learning conditions we need more information about cognitive disruption.

A common research paradigm to explore and find answers about our cognitive higher order functions is to give participants in the experiment a main cognitive task and present auditory distraction at the same time (Sörqvist et al. 2010; Beaman & Jones 1998; Hygge et al. 2003). Numerous experiments with such a paradigm have demonstrated many interesting phenomena. Jones with collegues showed that serial recall performance was more impaired by changing state sounds (like a, r, s, p, k, t, a, t) compared to steady state sounds (like a, a, a, a, a, a, a, a, a); this finding is known as the changing-state effect and is restricted to serial processing performance (Jones & Macken 1993). A changing state sound is not more disruptive than a steady state sound then the main task is free recall. Thus, when the main task involves processing of order, background sounds with ordered information (changing state) affect performance to a greater extent than continuous sounds.

A similar phenomenon in the field of auditory distraction is related to the semantic content of the background sound. When participants are told to recall visually presented items from the one semantic category (e.g. fruits), performance drops when the background sound contains words from the same semantic category (e.g. other fruits) compared to a sound that contains words from another semantic category (e.g. tools) (Neely & LeCompte 1999). This semantic effect is shown in free recall of the to-be-remembered words, but the semantic information gives no extra power to the distraction on serial recall performance (Jones & Macken 1993). Thus, when the main task is free recall, background sounds with semantic information from the same category as the to-be-remembered items affects performance to a greater extent than words from other semantic categories.

Many studies have explored cognitive functions like learning and memory (e.g. free recall, serial recall, recognition), proof reading, reading comprehension, reading speed etc. (Sörqvist 2010; Evans & Lepore 1993). Studies about counting are more infrequent, but there are some exceptions. Buchner et al. (1998) performed a series of four experiments where participants were instructed to count visually presented dots in four different experimental auditory conditions. In the four experimental conditions, an irrelevant auditory item was presented simultaneously with each visual dot (Irrelevant words, random number, distant numbers, and adjacent numbers). In the distant number condition the auditory distracting number were -20, -10, +10 or +20 from the current running total. In the adjacent number condition the distracting number was -2, -1 +1 or +2 from the current running total. They showed that performance in silence was significantly better than all experimental conditions but no significant difference between the experimental conditions was found. However, Buchner's experimental design has some weaknesses. The number of distracting items was equal to the number of dots, and the participant therefore could theoretically just count the distracting sounds to reach the correct answer.

The present paper describes two experiments on the topic of distracting sound during counting processing. Experiment 1 is basically a replication of Buchner et al. (1998). The approach in Experiment 2 was somewhat different, instead of presenting dots one after the other at a certain interval, all dots were presented at the same time. The benefits with such approach are that counting speed is not restricted to a certain interval, and number of distracting sounds is not related number of dots.

## EXPERIMENT 1

The purpose in Experiment 1 was to examine whether counting performance was affected by background noise. Three background noise conditions were used; spoken numbers, spoken numbers played backwards, occupations and silence as a fourth control condition.

## METHOD

### Participants

The experiment involved 32 subjects aged 18-34 years with a mean age of 25 years, 21 women and 11 males. The participants were recruited from the University of Gävle and received a cinema ticket in reward.

### Focal task

The counting task in the experiment was to count visually presented dots on a computer screen. The dots were presented one at a time with a presentation time of 700 ms for each dot and a 1.5 second pause between each dot.

### Background sounds

The spoken number background sound was two-digit numbers read by a male voice, the same sound files were played backwards in the backward number condition. In the third condition the same male read occupation words. All sound files were mixed in Audacity software.

### Design

The experiment had a within-participants design with one factor: “Background Sound Condition” which had four levels: spoken numbers, spoken numbers played backwards, occupations, and quiet. Each participant performed 15 counting trials in each condition, i.e. a total of 60 trials. The 60 trials were randomized. To control for potential order effects, the order of the sound conditions was counterbalanced across participants.

### Procedure

Each participant performed the test individually in front of a laptop and wore headphones throughout the whole experiment. Before they started the experimenter gave basic information about the experiment. Participants were instructed to ignore any sound that they heard in the headphones and were told that they would not be tested on its content. The written instruction in the beginning of the test, informed the participants that they would see a number on the screen (e.g. 34) which would be followed by a series of presented dots. Their task was to start from the presented number and keep on counting the following dots (for example, if the number 34 appeared on the screen, the first following dot were 35 and so on, if 10 dots were presented after number 34, the correct answer was 44, which should be typed on the keyboard). The experiment lasted approximately 30 min.

## RESULTS AND DISCUSSION

The results from Experiment 1 showed no significant effect of background sound, $F(3.31) = 1.48$, $p > .05$ (Figure 1). These results were in line with earlier studier with similar experimental paradigm (Buchner et al. 1998).

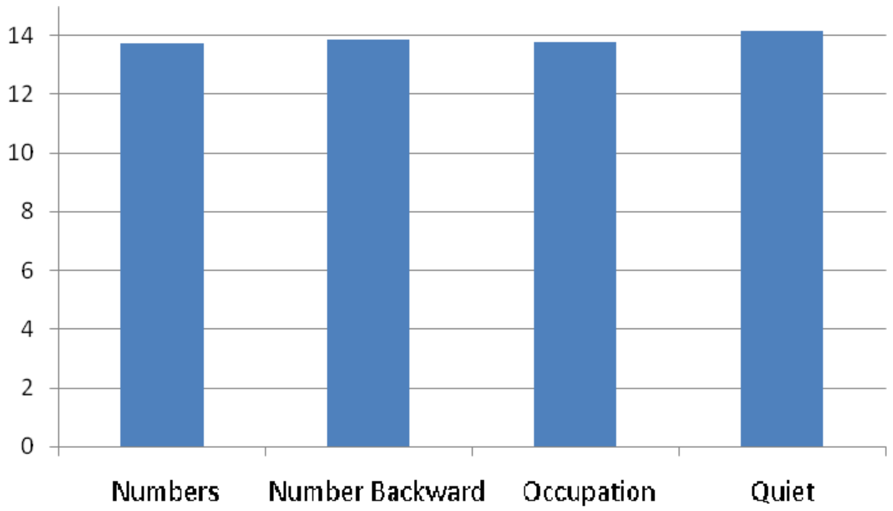


**Figure 1:** Mean number of correct counting results in the three experimental conditions and control (quiet). There was no significant difference between the conditions.

Counting performance has been shown to be unaffected by background noise in many studies. From a cognitive point of view the absence of effect of seems strange, since it's shown that other cognitive processes are affected by background noise with interfering content (e.g. semantic tasks as reading comprehension is negatively affected by background noise with semantic content, and serial processing is affected if the background noise contains ordering information). One possible reason to the absence of effect could the nature of the background noise. The counting task in Experiment 1 required the participants to count at a certain interval, which gave a counting rhythm. The background noise items were presented at the same rate so the actual rhythm could have been helpful for the counting. This interpretation could explain the absence of effect in Buchner et al's studies as well.

## EXPERIMENT 2

Experiment 2 was designed to separate counting speed from presentation rate of the background noise. When the rhythm of counting and the disturbing background sound is disconnected the counting process should be more vulnerable to the semantic information (numbers) in the disturbing background sound.

## METHOD

### Participants

Experiment 2 involved 32 subjects aged 18-32 years with a mean age of 23 years, 24 women and 8 males. The participants were recruited from the University of Gävle and received a cinema ticket in reward.

### Focal task

An image with dots was presented on a computer screen, the participants' task was to count the number of dots. The number of points in each image varied between 16 and 20. Each participant performed 15 counting trials in each condition, a total of 60 trials.

**Background sounds.** See Experiment 1

**Design.** See Experiment 1

### Procedure

Each subject performed the test individually in room in front of a laptop wearing headphones during the entire experiment. At the outset the participants were told about the experiment. Before they started the test program they read an instruction about the procedure. The written instruction in the beginning of the test, informed the participants that they would see a number on the screen (e.g. 34) which would be followed by an image with dots. Participant's task was to start from the presented number and keep on counting the dots on the image (for example, if the number 34 appeared on the screen, and there were 18 dots on the image, the correct answer was 52, which should be typed on the keyboard). The experiment lasted approximately 30 min.

## RESULTS AND DISCUSSION

The results showed a significant effect of background noise condition $F(3.31) = 7.49$, $p<0.01$, $\eta\ 2 = .195$ (Figure 2). Counting performance in the control condition was significantly better compared to all experiment conditions, Control vs. Occupations $t(31) = 2.35$, $p<0.05$; Control vs. Numbers $t(31) = 3.90$, $p<0.01$; Control vs. $t(31) = 2.56$, $p<0.05$ . The Number condition differed significantly from control condition and occupation condition $t(31) = 2.66$, $p<0.05$, but did not differ significantly from the backward number condition $t(31) = 2.35$, $p<0.05$. Neither did the backward number condition and the occupation condition differ significantly $t<1$.

These results are in line with the hypothesis that counting processing is affected by interference from irrelevant stimuli with number (or counting) information. These results give further evidence to the view of *interference by process*.

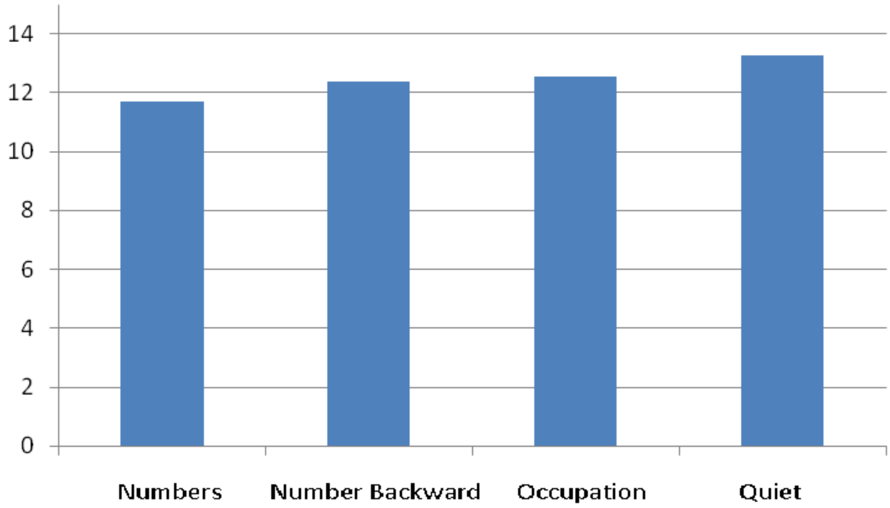


**Figure 2:** Mean number of correct counting results in the three experimental conditions and control (quiet)

## GENERAL DISCUSSION

This paper examined how different kinds of background noise conditions affect counting performance. When counting stimuli were presented one after another, no effect of sound condition was shown (Experiment 1). In experiment 2 another paradigm was chosen, all counting stimuli were presented at the same time in the same sound environmental settings. The result showed a significant effect of sound condition. All sound conditions had negative effect on counting performance compared to the quiet control condition. The spoken number background noise condition showed strongest effect, which was in line with the hypothesis.

Buchner et al. (1998) reported four experiments with different settings to examine the effect of background noise. They did not find any significant effect between the different background noise conditions in their studies. All four studies had more or less the same paradigm; they presented the counting stimuli one after another.

It has been shown that memory of serial order is effected by background noise, if the noise contains order information (Jones & Macken 1993). This kind of effect has also been shown for free recall performance when background noise contained words taken from similar semantic category (Neely & LeCompte 1999; Marsh et al. 2008).

Jones with coworkers has published more detailed evidence and discussions about the interference by process view (Marsh et al. 2009). Experiment 2 in the present paper gives further evidence to the process view, thus this view is applicable to counting performance as well as other cognitive tasks.

The reason that Experiment 1 in the present paper and Buchner et al. (1998) showed no significant differences between the background noise conditions on the counting performance, can be interpreted in terms of rhythm. Since the counting pace was equal as the pace of presented background speech stimuli no interference were occurred, and thus counting performance was unaffected.

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# Children's perceptions of classroom noise: self-reported data from clinical and non-clinical populations

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## INTRODUCTION

The many possible adverse effects of classroom noise on a student include reduced ability to consistently hear the teacher's voice, and reduced capacity to attend to and remember longer and more complex utterances. These effects may be magnified for a student with an auditory processing disorder (APD). A diagnosis of APD implies that the student has less ability than his/her age peers to successfully resolve auditory input. This may arise because of perceptual deficits, however cognitive deficits related to language competency, attention and working memory may also undermine a student's ability to make optimum use of auditory input. APD is typically described in terms of numerous observed deficits (signs) in affected children, such as markedly poor listening skills, poor comprehension of speech and need for repetition, slow responses when spoken to, distracted or 'dreamy' behavior and frequently misunderstanding or forgetting oral instructions. These difficulties usually become more apparent in noisier and more reverberant listening environments such as classrooms and shopping centers.

The complaint behavior (symptoms) of children with APD has received little attention. There is a general assumption that all children with APD are bothered by noise, to a greater or lesser extent. If this is the case, are their complaints uni-dimensional or do affected children express other symptoms in a multi-dimensional way? Further, do these complaints assist in distinguishing children with APD from children without APD or differentiate sub-types of APD? The aim of this poster is to present the complaint behavior of children referred to a specialist APD clinic based on their reported perception of how they experience listening and learning in their classroom.

## METHOD

*Sample*: We report the results of qualitative data elicited from 265 consecutive children, age 7-17 years (mean age: 10.02 yrs; SD: 2.3 yrs), seen in one of the APD Clinic of Flinders University from 2004 to 2010. All children completed a 4-test AP test battery (2 dichotic tests and 2 tests of short term auditory memory) and were diagnosed with an APD if their results on 2 or more of the 4 tests fell below normal limits (> 2 SDs below age mean). 162 of the 265 referred children met criterion for APD (110 of the 179 boys [61.5%] and 52 of the 86 girls [60.5%]). At the end of the test battery, as a standard part of the clinical assessment, all children participated in a semi-structured interview (8-9 standard questions) with the audiologist.

*Data collection*: We report the children's responses to the following 4 questions related to classroom noise and to a visual analogue scale (VAS) activity called "the noise ruler." (Preliminary opening question to the interview: "How do you find hearing and listening in your classroom?)

Q. 1 “Tell me about noise in your classroom.”
Q. 2 “Does the noise affect you?/How does the noise affect you?”
Q. 3 “Would you like your class to be quieter?”
Q. 4 (If Yes to Q. 3), “Why would that be better for you?”
The noise ruler, hand-drawn at the time and explained to the child, was then presented. The VAS was verbally and visually labeled 0 at one end, “silent”, and 10 at the other end, “extremely noisy.” First, a child was asked to mark the line at/around the noise level at which he/she *perceives* the class to be *most* of the time (m) and then in the same way to indicate where he/she would *prefer* the classroom noise level (p) to be, again most of the time. After each response the child was asked to express a numerical value between 0 and 10 for each noise level marked. See examples.

RESULTS

*“Noise Ruler”*: Children with APD perceived classroom noise to be louder than the referred children who did not meet the diagnostic criterion [non-APD children] (mean VAS levels 7.00 vs 6.64). This difference did not achieve statistical significance ($p = 0.21$). Children with APD also would prefer classroom noise levels to be lower than non-APD children ($p=0.028$) and the difference between the perceived and preferred levels was also significantly different for the two groups, $p = 0.021$ (unpaired t-tests). There were strong correlations with age for measures of both perceived and preferred noise levels with younger children perceiving classroom noise to be significantly louder ($p<0.001$) and preferring lower noise levels to older children ($p<0.001$, Pearson correlation)

We examined the relationship between the diagnostic outcome “severity” scores (non-APD = 4 and APD = 6-10) for 234 children with complete test data and noise ruler scores. Correlations of VAS results with severity were significant for both the *perceived* noise level ($p = 0.043$, 1 tailed) and for *preferred* noise level (inverse correlations, $p = 0.011$, 1 tailed, Pearson correlation).
*Interview questions*: Twenty four percent (24.2%) of children voiced no concerns about classroom noise or any noise specific effects. The remainder volunteered concerns about noise that were *post hoc* aggregated in the following four domains:

1) Physical effects, e.g. headaches, ears hurting (15.5% of children)
2) Mental effects, e.g. annoyance, distraction, frustration, arousal and anger (28.7% of children)
3) Inability to concentrate and/or work optimally (41.9% of children)
4) Inability to hear and/or listen well (42.7% of children)

The non-APD children were significantly more likely to express no concern about noise than the children with APD ($p = 0.007$, Fisher’s exact test, 2 tailed). When compared for specific noise effects the APD and non-APD groups showed no statistically significant differences with respect to self-reported physical effects of noise ($p = 0.60$), mental effects of noise ($p = 0.40$) or inability to concentrate and work in classroom noise ($p=0.124$). However, children with APD were much more likely than non-APD children to report difficulties hearing and/or listening in class ($p = 0.007$).

### Comparison with results for non-referred school age children

Kilcoyne (2004) assessed 125 children (64 girls and 61 boys) age 7.7 yrs to 11.3 yrs (mean 9.8 yrs, SD 0.9 yrs) in 5 schools in metropolitan Adelaide using a VAS and a semi-structured interview to ascertain the perceptions of classroom noise in a sample of non-referred children. Children with known hearing impairment or current middle ear problems were excluded from the sample. The study method was as described above. The VAS results for this sample showed a significant difference between the children's perceptions of classroom noise *most* of the time (mean: 5.90, SD = 1.95) and preferred level of classroom noise most of the time (mean: 2.81, SD = 1.84) ($p<0.001$). The VAS responses were independent of gender, age and year level.

The non-referred children and the non-APD children differed significantly on the *perceived* level of classroom noise on the VAS ($p=0.01$), however, there was no significant difference for this measure between the children with APD and the non-APD group ($p=0.215$). In contrast, the non-referred children and the non-APD children did not differ in terms of their VAS responses for *preferred* noise levels ($p=0.80$), but, as reported above, the non-APD children differed significantly from the children with APD on the *preferred* noise level ($p=0.028$, unpaired *t*-test).

## CONCLUSIONS

1. The referred children, those with APD as well as the non-APD children, perceived classroom noise as significantly louder on a VAS than the non-referred children. Younger referred children, irrespective of diagnosis, expressed more problems with classroom noise than older children using the VAS.

   This finding lends support to a broadly based, non-restrictive referral policy for AP assessment. The referred children differ significantly from non-referred peers with respect to their perceptions of classroom noise and its effects. Clinical assessment which includes an interview allows the child to articulate his/her problems, thereby enhancing understanding of the child's difficulties and stimulating better targeted classroom management.

2. The children with APD differed significantly from the non-APD children on 2 of 3 measures using the VAS and for self-reported difficulties hearing and listening in classroom noise.

   These findings suggest that children with APD are especially vulnerable to noise effects. Further investigation of this interaction may help to elucidate the nature of APD, which remains elusive. Experiments with good ecological validity conducted outside of the clinic may complement psychoacoustic studies of noise effects.

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# Metrology of subjective reaction to noise through performance evaluation

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## ABSTRACT

It's well known that sound and noise have influence on humans, in terms of enjoyment, annoyance or damage. It's particularly interesting to quantify the influence of auditory stimuli when a subject is carrying out an activity that may require attention and accuracy.

We designed and carried out an experiment with the purpose of judging the performance of subjects engaged in a visual task, by comparing two different environmental conditions: silence and noise.

This experiment, set up in semi-anechoic room, involved 25 subjects of both sexes and aged between 22 and 75.

Data analysis has been conducted in order to 1) highlight any variation in the subject's performance accuracy in the presence of disturbing noise and 2) investigate the influence of the noise on reaction time. These results were also compared with information collected by a questionnaire.

## INTRODUCTION

The attempt to determine, quantify and measure the effects of external stimuli in humans requires the synergy of both scientific and humanities fields and a consequent interpretive synthesis that transcends the boundaries of the search field of metrology as commonly understood.

In 2006 the European Commission gave emphasis to this issue with the establishment of an international research project characterized by a strong interdisciplinary approach that has taken the name of Measuring the Impossible Network, in the context of the New Emerging Sciences and Technologies (NEST) and with the aim to extend metrology in innovative research fields. The measure of subjectivity is one of the objectives sought by the Soft-Metrology, defined as "the set of techniques and models that allow objective quantification of the properties determined by the perception in the domain of all five senses". The ambitious project to measure the impossible, namely to quantify, through methods typical of the measurement science, the phenomena identified as subjective, is expected to define quantitatively variables such as, for example, satisfaction, usability, comfort, and many others.

In a nutshell, we need to identify and interpret the objective changes that occur in humans as a result of certain sensory stimuli. The main question that we try to answer may be as follows: if the stimulus is a sensory input metrologically quantifiable (a sound, a flash of light, a roughness...) which output can be measured once filtered through the senses and interpretation of the subject?

According to the tools and analytical models currently available, we can identify three main types of output, which we define as: 1) opinion, 2) physiological response, and 3) performance.

The opinion of a subject about an object or an event related to the sensation caused by them can be investigated through appropriately designed questionnaires. A series of questions related to a scale submitted to a sufficiently large panel, can provide meaningful answers for understand how a given phenomenon is perceived.

Another way to investigate the subjective response to a stimulus is to identify some physiological parameters of organs that can be monitored and measured. For example, indicators of cognitive load, attention, or stress are the pupil diameter, heart rate and skin conductivity. Over the last decade, the neuroscientific disciplines have given great importance to the techniques of functional magnetic resonance imaging to monitor brain activity.

The third and final output of the interaction between humans and the world that we intend to quantify is the performance. This is assessed by measuring changes in the attitudes of the subject to perform a specific task, such as reaction time to a stimulus or accuracy in performing a given action.

We believe that the integrated analysis of these three main outputs allow to obtain "objective" information, both quantitative and qualitative, about the "subjective" response at a specific sensory stimulus.

Since this integrated approach to the problem of human perception is strongly multidimensional, a multidisciplinary perspective to the problem is highly desirable. The tools offered by Metrology - in addition to define and quantify measurands accurately allow us to study the appropriate method to correlate the results obtained and identify the reliability margins of different interpretations.

## OUR EXPERIMENT

Given the general conditions described in the introduction, we decided to set up an experiment designed to investigate the influence of environmental disturbances on the performance of individuals engaged in a simple visual task. It's well known how sounds and noises generate a feedback in the human feelings in terms of enjoyment, annoyance or harm. It becomes particularly interesting to evaluate the influence of sound stimuli, noise in our experiment, when a subject is intent on carrying out activities that may require attention and accuracy, like visual task.

### Experiment set-up

The experiment, arranged in a semi-anechoic room, involved 25 subjects of both sexes and aged between 22 and 56 years. In Figure 1 we show a schematic representation of the experimental set-up. The person involved in the test was placed at a distance of 0.5 m from the computer monitor. A dodecahedric sound source generating a particular background noise was placed behind him.

As shown in the picture, the monitor was also flanked by two sources of glare, an incandescent light source and a LED one, because the influence of visual sources of disturbance was also investigated. Here, however, we will describe the trial investigating the influence of sound.

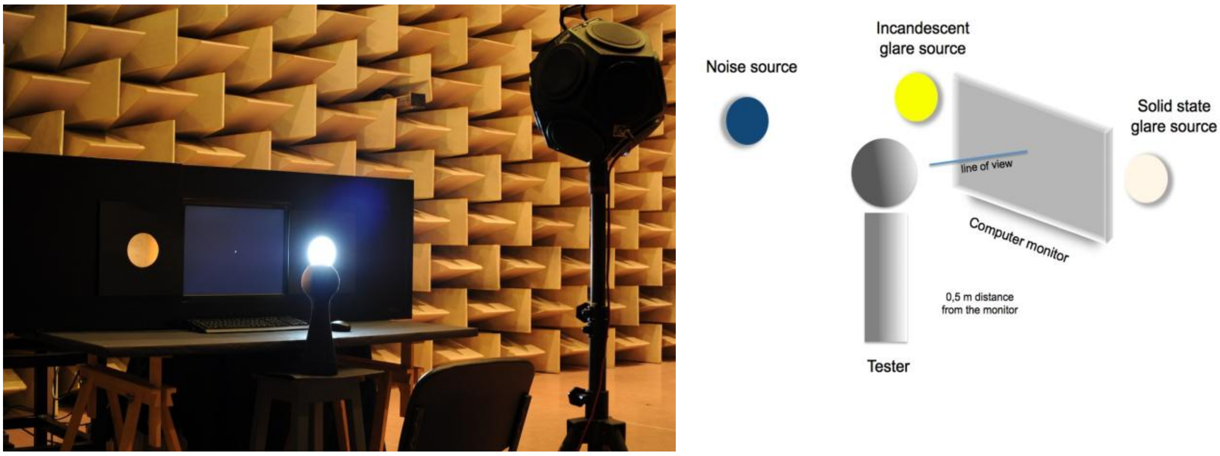


**Figure 1:** Experiment set-up picture and schematic representation

The test, conducted in darkness and divided into several sessions of about 5 minutes each, consisted in the identification, by each subject and with the click of a mouse, of small targets square shaped and of different contrast on the monitor, in a maximum time of 60 s. Subsequent to the identification, the subject was then asked to drag the identified targets in order to form a sequence ordered by contrast, decreasing the negative to the positive and growing, as exemplified in Figure 2.

**Figure 2:** Correct target sequence ordered by contrast

This task (target detection and then ordering) was carried out either in silence or in the presence of noise. To each subject, at the end of the test, was then asked to provide a self-evaluation about their performance. Referring to the test conditions in which there was background noise compared to those carried out in silence, subjects were asked to express an opinion on what they thought had been the influence of this noise on their accuracy in performing the visual task assigned.

The subjects, following the pattern tree shown in Figure 3, could say whether they had received some influence and, if so, whether in terms of improvement or worsening, while also providing an information about this influence magnitude.

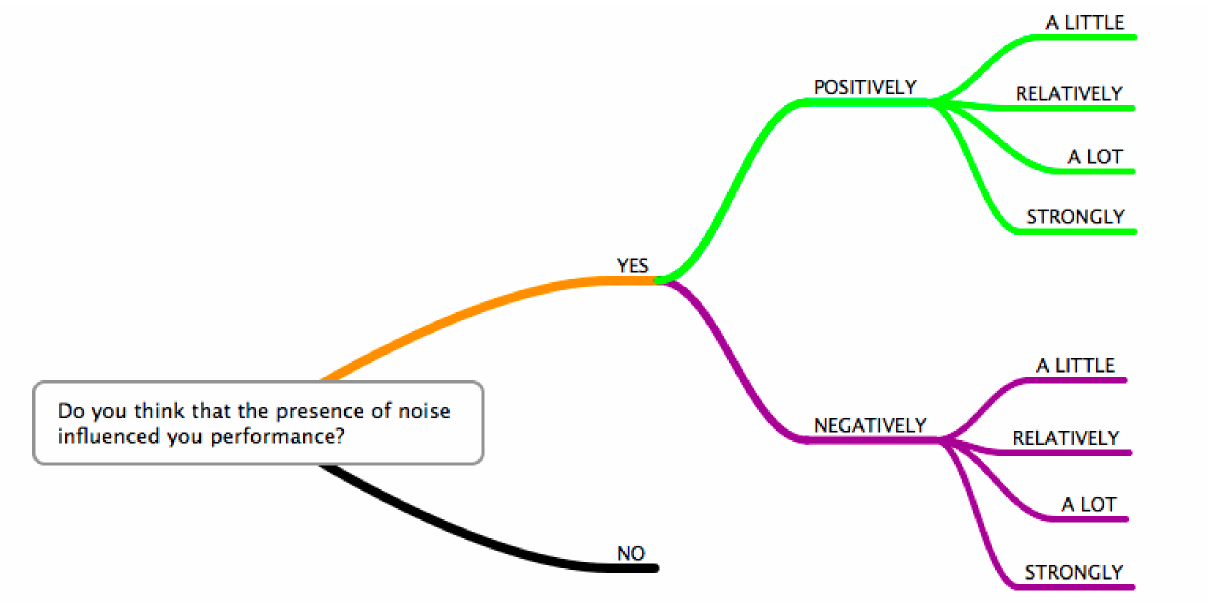


**Figure 3:** Questionnaire proposed to subjects at the end of the test

## The stochastic noise

In the design phase of the experiment described here, in order to identify a noise that could highlight the best possible influence on humans, some preliminary tests have been conducted.

Some subjects have been asked to detect visual targets both in silence and in a noisy condition. We used a pink noise, a series of sounds with informational content (ambient noise, radio messages, phone rings, etc..) and a pink noise to which was added an artificial disturbance unrelated to the common experience, an infinitely ascending scale, i.e. the acoustic illusion of Shepard scale (Shepard 1964).

Based on a preliminary analysis of collected data a general tendency for subjects to improve their performance in the presence of background noise has been noticed. For this reason we decided to deepen the investigation.

However, it is known that the human brain is able to adapt quickly to a stress condition. It is possible that an auditory source of disturbance, with particular characteristics of predictability and monotonicity, after a short administration period, can be "masked" by the human ear and thus lose its influence.

Due to this, based on some recent studies (Ball 2010), it was decided to compose a noise that can be as refractory to this suppression as possible. One of the hypotheses suggested by Ball is that our brain is more adaptable to different types of noise for which it is able to "anticipate" their evolution. For example, a classical symphony "meets" the brain processes that can predict, within certain limits, the evolution of the melody. Ball argues that this is one of the main reasons why the contemporary music is very often considered unpleasant: our brain cannot predict its evolution, generating in the listener a kind of stress or discomfort.

For the proposed test a sound of stochastic nature has therefore been specially composed and generated, consisting of 100 frames of sinusoidal signals with frequencies between 10 Hz and 10 kHz, which turn on and off at random intervals with a minimum of 0.25 s. The overall sound pressure level was 78 dBA, so as to exceed the threshold of 60 dBA identified by Saeki et al. (2004) in their experiment that aimed to investigate the minimum sound level to obtain an influence in human.

Figure 4 shows the sound pressure level of stochastic noise used during the test. The decision to administer a sound like this was prompted by the desire to create disorder and confusion in the subject engaged in test, because of the highly variable and unpredictable nature of this sound that does not allow or minimize the masking effect.

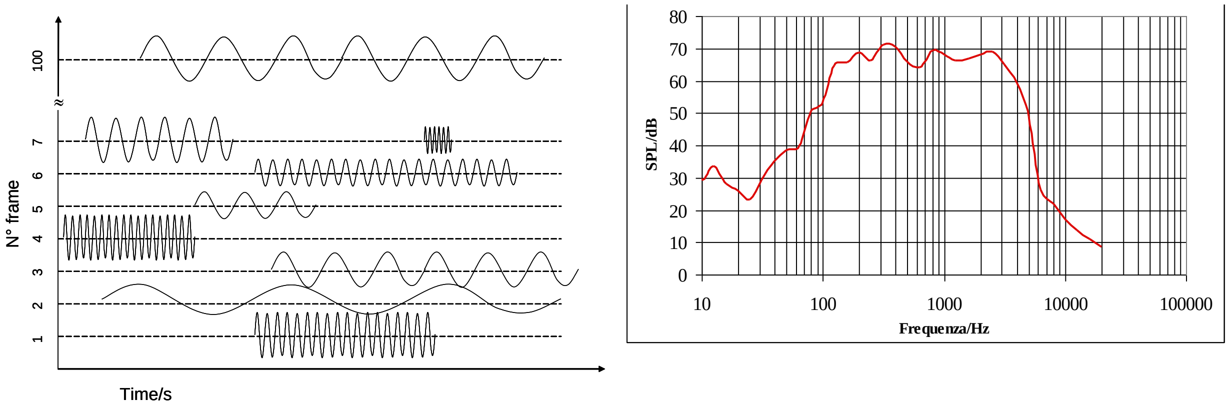


**Figure 4:** Schematic representation of stochastic noise and its sound pressure levels

## MEASURAND IDENTIFICATION AND OBJECTIVES

In our experiment we considered the following measurands:

- Number of correct answers;
- Number of false positives;
- Time: 1) to conduct the entire test, 2) reaction to the first stimulus, and 3) between a target and identified the following;
- Number of errors in ordering targets by contrast;
- Correlation between self-evaluation (questionnaire) and performance.

Regarding the number of correct answers, we considered the percentage of targets identified in the first phase of testing. As mentioned above the targets presented were different in contrast and position. Was then monitored the threshold of contrast perception and therefore given the number of targets identified in the total submitted.

About the second measurand, we considered as "false positive" each click of the mouse that the subject did in a wrong position on the screen where no target was presented.

Time evaluation has been center of the analysis of data obtained from this test. Temporal variations between silence and noisy condition have been considered regarding: 1) the total time required to perform the task, 2) reaction to the first stimulus (i.e. the time between submission of the screen with target and the first click of the mouse made by the subject) and 3) the average time between a mouse click and the next one.

The penultimate parameter considered for the measurement of subject performance has been the accuracy degree with which the target ordering by contrast was made. In fact, although the ability to discern small differences in color - shades of gray in this case - is a visual property that is more or less influenced by ambient lighting conditions, the degree of precision with which the subject performs this operation is also the result of attention and concentration that may indeed be affected or not by the presence of sound noise.

The last measurand concerns the correlation between the self-evaluation that the subject provided by questionnaire at the end of the test compared to his performance evaluated according to the criteria previously described.

It therefore intends to improve the performance increase in positive responses as well as the decrease of false positives, the shortening of reaction time and the average time between a response and then the other as precisely the sort of carrying stimuli. Upon the occurrence of the opposite conditions of course we mean that the performance has worsened. We refer to the last section of this paper for a specific study on future developments of this approach.

## FIRST DATA ANALYSIS AND RESULTS

For the results analysis a preliminary investigation about the influence of subject ages on the parameters chosen was carried out and it was therefore decided to divide the sample into two groups (Group I: aged between 20 and 30, Group II: between 35 and 55).

Regarding the first measurand (total number of targets identified) we made a comparison between the experimental sessions took in silence and in the presence of noise. In this case the group of subjects was considered as a whole and, as shown in the histogram shown in Figure 5, in the presence of noise there is an increase of 35 % in the number of targets identified.

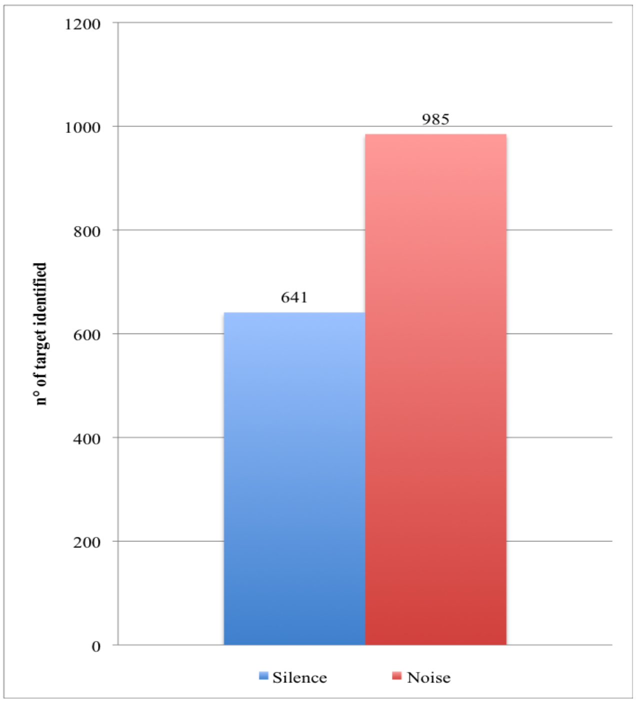


**Figure 5:** Total number of identified targets in the two different environmental conditions

Regarding the number of false positives and the duration of the entire test, there was no significant difference between the two experimental conditions (silence and noise). On the contrary, interesting results have been obtained for the other two time parameters.

Considering the distinctions of subjects by age, which in this case is significant, we note that the reaction time to the first stimulus, and the average time between the selection of a target and the subsequent, decrease with the addition of noise.

As shown in Figure 6, was in fact registered a decrease of 25 % for group I and 43 % for group II, in the reaction time to the first stimulus at the transition from silence to noisy condition. Similarly (Figure 7) a decrease of 13 % for both groups was noted regarding the average time between the selection of a target and the next one.

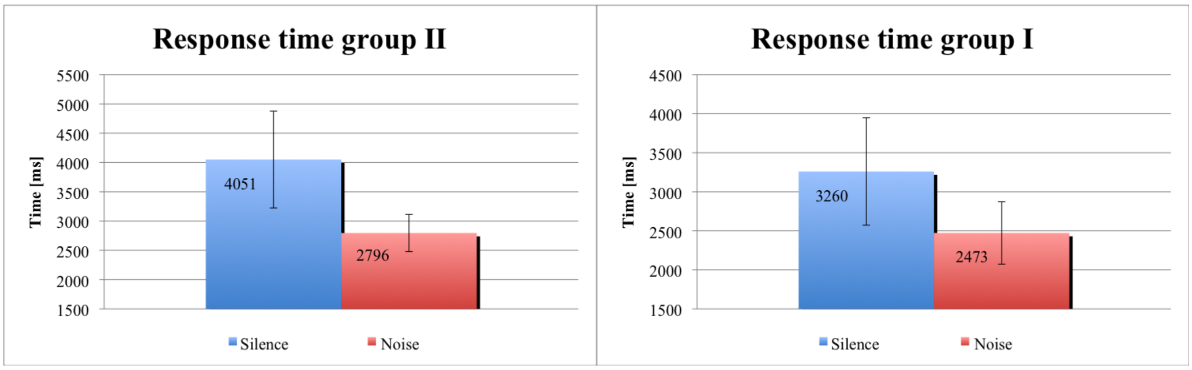


**Figure 6:** Comparison between response time in silence and in noisy condition for the two subjects group (group **I**: age between 20 and 30; group **II**: age between 35 and 55)

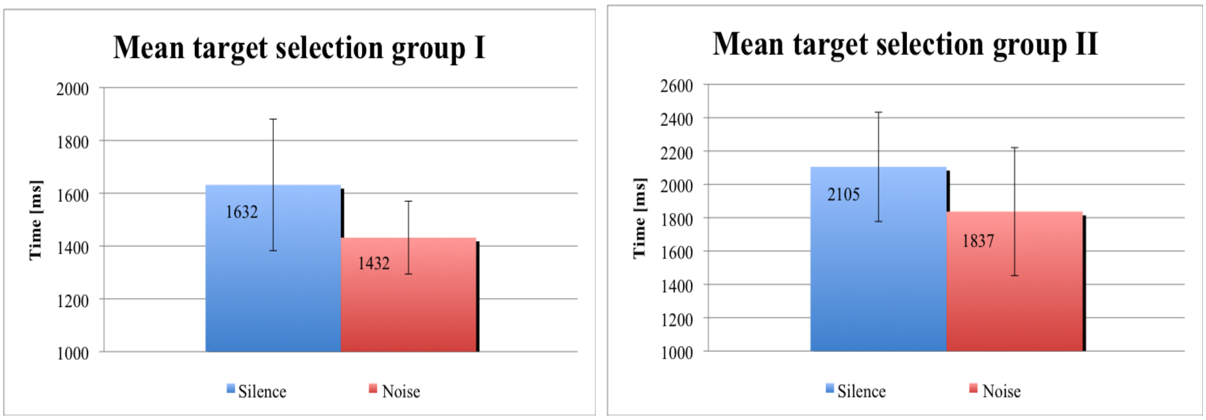


**Figure 7:** Comparison between mean target selection time in silence and noisy condition for the two subjects group (group **I**: age between 20 an 30; group **II**: age between 35 and 55)

The final consideration about the data analysis concerns the evaluation of the accuracy with which each person has ordered the target by contrast. In this case a significant difference in subjects performance between the two environmental conditions, was noted for at least half of the testers, such as highlighting that the presence of noise actually influences the development of this task, for someone positively and for others negatively.

We then wanted to correlate this result with subjective data about performance self provided by the person in the questionnaire with the intent to verify a match. The chart presented in figure 8 shows, for each subject, if the performance has worsened or improved in the transition from silence to noise, together with the same information obtained by self-evaluation (questionnaire).

This comparison show that about 20 % of the subjects provided self-assessment of their performance is consistent with the measured data. The remaining sample showed peculiarities in certain situations would be dealt with case by case basis. Some people in fact have underestimated the influence of noise on their performance and others gave an opinion opposite to the observed reality. For the realization of this plot was used only the information concerning the parameter relating to the correctness of sort of targets. We think it is interesting to investigate this issue by including other results that are unified in a single index, can be directly correlated with the self-assessment and provide more precise information regarding the effectiveness of this technique in this context.

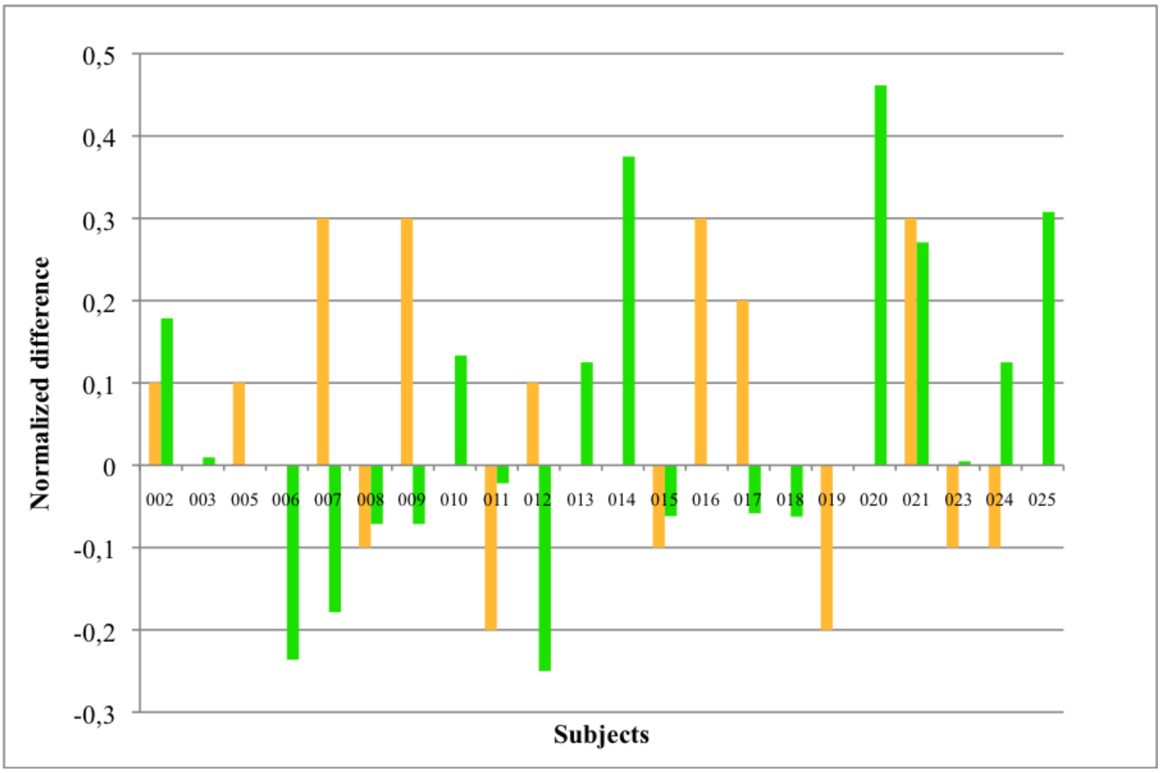


**Figure 8:** Correlation for each subject between self-evaluation (yellow columns) and performance (green columns)

## CONCLUSIONS

Through the use of metrology tools, the intent of our work is to investigate the different techniques of quantification of subjective response to stimuli, in order to provide useful information for the optimal method of investigation in various fields of human perception. In the case of this experimental research, future development will be to establish a "performance index" that takes into a suitably weighted account, all the parameters identified as significant for defining the characteristics of a human performance. As for the aspects strictly related to auditory perception, we will instead investigate the influence of different nature and level of noise.

The ultimate goal is to provide new tools to soft metrology to be used in various fields, from experimental psychology to the design of effective human-machine interfaces, or the characterization in terms of subjective evaluation of objects, materials and environments.

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# Comparison of five speech masking sounds - a laboratory experiment

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## SUMMARY

The purpose of this study was to find out what kind of features should be preferred and avoided when using speech masking sound in open-plan offices. Fifty-four subjects were tested in seven sound conditions: speech, silence and five masked speech conditions. The five masking sounds were filtered pink noise, ventilation noise, instrumental music, vocal music and the sound of spring water. They were superimposed on speech. The masked speech conditions corresponded to an acoustically excellent open-plan office in respect of the Speech Transmission Index (STI 0.38). The speech condition (STI 0.62) corresponded to an STI obtained between nearby workstations in an acoustically poor open-plan office. Silent condition (STI 0.00) corresponded to the STI measured between two nearby private office rooms. In each of the seven sound conditions, the subjects performed a short-term memory task, a proofreading task and a creative thinking task and completed a questionnaire on acoustic comfort. Compared to the silent condition, short-term memory performance deteriorated in speech condition and in most masked speech conditions. Compared to the speech condition, performance improved when speech was masked with spring water sound. Ratings of acoustic satisfaction and subjective workload showed that the masked speech conditions subjectively improved the working conditions compared to the speech condition. Overall, the performance results and subjective perceptions showed that the spring water sound was the most optimal speech masker whereas vocal music produced negative effects similar to those of speech.

## INTRODUCTION

Most office workstations are located in open-plan offices although the occupants often suffer from distracting noise and lack of speech privacy (e.g. De Croon et al. 2005; Pejtersen et al. 2006; Haapakangas et al. 2008; Kaarlela-Tuomaala et al. 2009; Bodin Danielsson & Bodin 2009; Jensen et al. 2005). Speech from adjacent workstations is the most distracting type of noise.

The benefits of open-plan offices are numerous and easy to translate into economical terms, e.g. space efficiency, flexibility, and ease of ad hoc communication. An acoustic consultant, who is aware of the disadvantages of open-plan offices, can always suggest the use of private office rooms when the work requires high privacy and concentration. However, the benefits of open-plan offices are so evident that private office rooms are seldom used instead of open-plan offices. The acoustic consultant must, then, take care of proper room acoustic design in the open-plan office.

Recent studies provide means for creating high speech privacy with room acoustic design. These include, in short, high absorption in the ceiling, walls, screens and storage units, high screens between workstations, textile floor coverings, acoustic division between nearby teams, and the use of speech masking sound.

For many decades, speech masking sound has been used in open-plan offices, ships and other places where acoustic division is not possible by walls. Hongisto (2008) has published a field study which shows some benefits of speech masking.

Speech masking is based on the use of sound which covers speech to a sufficient degree so that the speech intelligibility of nearby speech is reduced. The sound pressure level is typically adjusted to 40...45 dB ($L_{A,eq}$) which is a level that does not hamper normal conversations at short distances but still produces efficient speech masking.

In most commercial applications, filtered pink noise, or related non-natural sound is used. Filtered pink noise sounds like ventilation. It is spectrally comfortable and quite easy to habituate to. It is often suggested that alternative masking sounds should be tested since they might be more comfortable in the long run.

The aim of this study was to find out what kind of masking sound is most optimal in terms of cognitive performance and subjective comfort. Psychological research methods were applied in assessing these effects.

This paper is a shortened version of Haapakangas et al. (2011).

## MATERIALS AND METHODS

### Subjects

Fifty-four university students were recruited for the experiment. Subjects were 19 to 45 years old (mean=26; SD=5).

### Comparison of 16 masking sounds - a pre-experiment

The main experiment was preceded by a pre-experiment. Its purpose was to screen a variety of potential sounds and select the most interesting ones to the experiment. The pre-experiment included the following 16 masking sounds: four differently filtered pink noises, three different ventilation sounds, two vocal music samples with slow tempo, two vocal music samples with fast tempo, instrumental music, road traffic noise measured behind a facade in a room, one commercial melodic masking sound, sound of spring water and babble caused by 20 persons talking in a café (non-intelligible multi-speech). The sounds were tested with 11 persons in an office laboratory using three-minute exposure times. Subjective perceptions were measured with the same acoustic satisfaction questionnaire that was used in the main experiment. It was administrated after each masking sound. The most satisfactory sounds were spring water, instrumental music, ventilation, traffic noise and the pink noise spectrum with a slope of - 5 dB/octave, in this order. Vocal music was the least satisfactory, particularly with Finnish (native language) lyrics and fast tempo.

### Sound conditions

Five masking sounds were selected to the main experiment: filtered pink noise, ventilation, vocal music (i.e. instrumental music containing lyrics), instrumental music and spring water sound (Table 1, Figure 1). The first four sounds are typical speech maskers in, for example, offices and health care premises. The fifth represents a natural sound which may be more preferable than artificial sounds.

In the experiment, the masking sound was always played together with speech. The reference sound conditions were silence and speech without masking sound. The total number of experimental conditions was thus seven. STI and sound pressure levels were determined in workstations according to ISO/DIS 3382-3.

**Table 1:** -weighted sound levels of $L_S$=speech, $L_N$=masking, $L_{tot}$=total level of speech and masking, and $L_{SN}$=speech-to-noise ratio. STI=Speech Transmission Index

| **Name of sound condition (abbr.)** description | $L_S$ [dB] | $L_N$ [dB] | $L_{tot}$ [dB] | $L_{SN}$ [dB] | STI |
|---|---|---|---|---|---|
| **silence (silence)** speech and masking absent | - | 37 | 37 | -¥ | 0.00 |
| **speech (speech)** highly intelligible speech, masking absent | 48 | 37 | 48 | 10 | 0.62 |
| **filtered pink noise (pink)** speech masked with filtered pink noise | 45 | 46 | 48 | -1 | 0.39 |
| **ventilation noise (ventilation)** speech masked with ventilation noise | 45 | 45 | 48 | 0 | 0.37 |
| **instrumental music (instrumental)** speech masked with instrumental music | 45 | 45 | 48 | 0 | 0.35 |
| **vocal music (vocal)** speech masked music containing lyrics | 45 | 45 | 48 | 0 | 0.36 |
| **spring water sound (water)** speech masked with spring water sound | 45 | 45 | 48 | 0 | 0.40 |

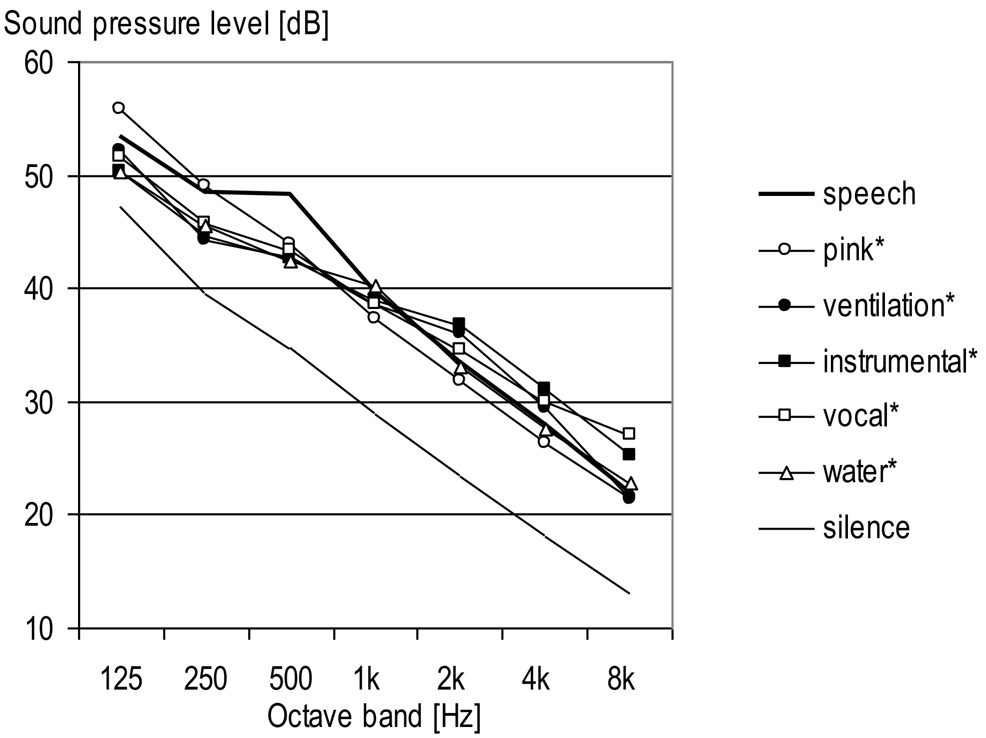


**Figure 1:** Octave band spectra of the seven sound conditions. The spectra represent equivalent sound pressure levels recorded in the workstations.

### Laboratory

The experiment was carried out in a laboratory resembling a normal office room (Figure 2). The speech was produced from loudspeakers in empty workstations (S1-S4). Masking sound was produced from loudspeakers above suspended ceiling (M1-M5).

### Questionnaire

Acoustic comfort was measured with a questionnaire that was administered after each sound condition. It included 16 items that measured different subjective aspects of the sound condition. Sum variables were formed for the analysis (acoustic satisfaction 12 items, subjective workload 4 items). The questionnaire also included an assessment of arousal and ratings of disturbance caused by different noise sources.

### Performance tests

Three tasks were used. In the serial recall task, subjects had to recall visually presented digits from 1 to 9 in the order of presentation. The task contained 10 sequences. The percentage of digits not recalled in their correct positions was calculated for each sequence. The average score from all 10 sequences (mean error rate) was analysed. This task is a classic task for studying cognitive effects of noise.

In the creative thinking task, the subjects were instructed to write down as many alternative uses for a given object as possible in 5 minutes. They were presented with one name of an object (e.g. 'potato') on a paper and the common use of the object was given. Two dependent variables were formed for the analysis: ideational fluency and ideational originality.

In the proofreading task, subjects marked mistakes in a text containing 60 errors. Half of the errors were spelling errors and the other half contextual errors. The time limit was 10 minutes. The total number of correctly found errors was analyzed.

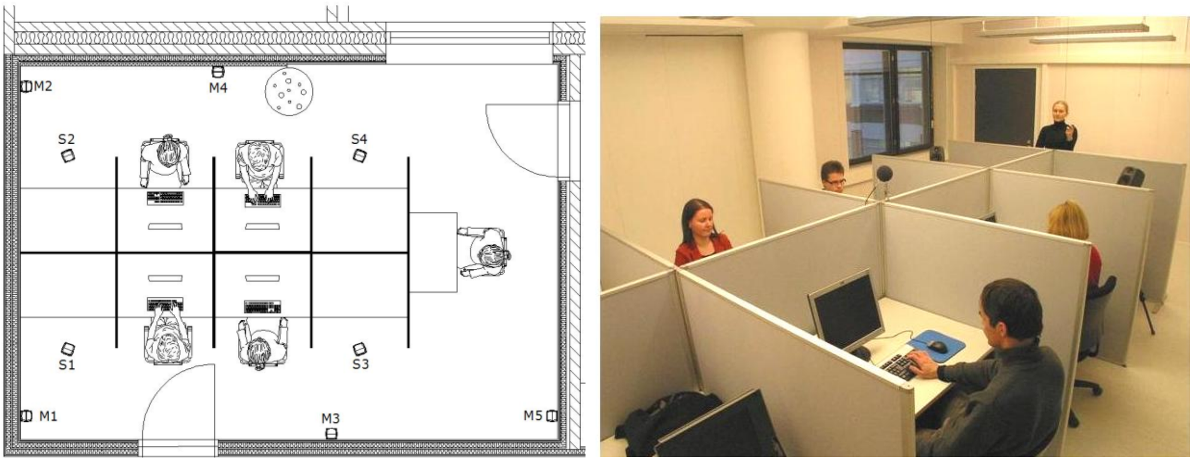


**Figure 2:** Layout and photograph of the laboratory.

### Experimental design

The study was a repeated measures design, i.e. all subjects took part in all seven sound conditions, thus acting as their own control. Three to four subjects were tested at a time (altogether 14 test groups). The sound conditions were presented in a quasi-random order for the test groups. In each sound condition, subjects performed the three above-mentioned tests. The task performance and the subjective perceptions of the sound conditions were the dependent variables.

**Procedure**

The experiments were conducted in May 2008. The experiment lasted 4½ hours. Half of the subjects were tested from 8 a.m. to 12.30 p.m. and the other half from 1 p.m. to 5.30 p.m. Before the experiment started, subjects were informed that the study dealt with performance in an office-like environment. Subjects filled in the questionnaire gathering background information. This was followed by a 30-minute practice session of the tasks in silence. Before the actual experiment started, subjects were instructed to ignore the sounds and concentrate on the tasks. The experimenter switched on the masking and speech sounds, and then said which task the subjects should start. After the tasks had been completed, the experimenter turned off the sounds. Each sound condition lasted approximately 25 minutes, and was followed by the questionnaire (5 min) before the next sound condition began. A ten-minute break was given after the 1st condition and again after the 4th sound condition. Subjects were informed in detail about the aim of the study after the experiment.

**Statistical methods**

SPSS 16.0 (SPSS Inc., Chicago, Il, USA) was used for the statistical analysis. A repeated measures ANOVA and t-tests were used for variables that were normally distributed. In the serial recall, only data from 26 subjects is reported here (a complete analysis of the data is reported by Haapakangas et al. 2011)

RESULTS

Serial recall task was significantly affected by the sound conditions (Figure 3a, $F_{6,150}$=4.42, $p$<0.001). Comparisons of the five masked speech conditions indicated that spring water sound improved performance in comparison to vocal music ($t$(25)=3.3, $p$=0.021, two-tailed) and ventilation noise ($t$(25)=2.7, $p$=0.039, two-tailed). Spring water was the only masking sound that produced a statistically significant improvement in comparison to unmasked speech ($t$(25)=2.5, $p$=0.035, one-tailed). All conditions were also compared to silence, revealing that performance was better in silence than in unmasked speech ($t$(25)=2.8, $p$=0.02, one-tailed) and in three masked speech conditions, namely the conditions with vocal music, ventilation noise and filtered pink noise ($p$<0.05). Spring water sound and instrumental music performed well as speech maskers as they did not differ significantly from silence.

In the creative thinking task, a marginal effect of sound condition was observed for the subjects' ideational originality ($F_{6,306}$=1.93, $p$=0.075, Figure 3b), with slightly increased performance observed in the spring water sound condition. Proofreading performance was not affected by the sound conditions ($p$=0.17).

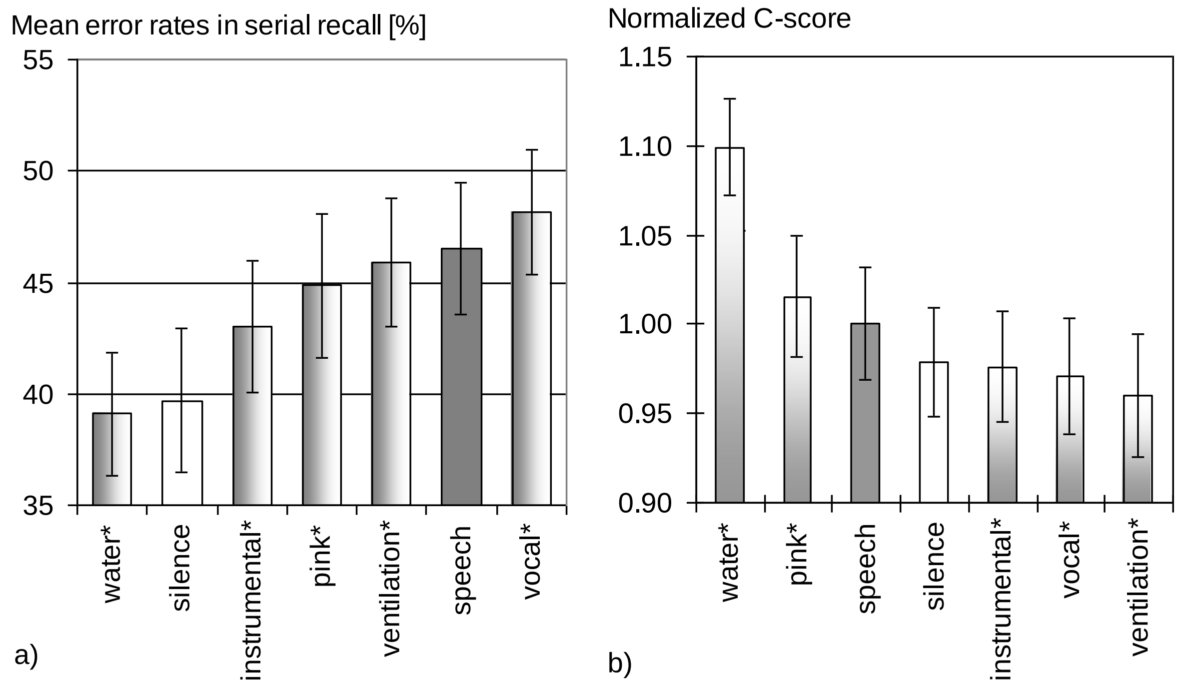


**Figure 3:** a) Error rates in serial recall task in seven sound conditions. b) Ideational originality of creative thinking task in seven sound conditions. Values above C=1.00 represent higher than average creativity. Lines represent standard errors.
Sounds with an asterisk (*) were played together with speech.

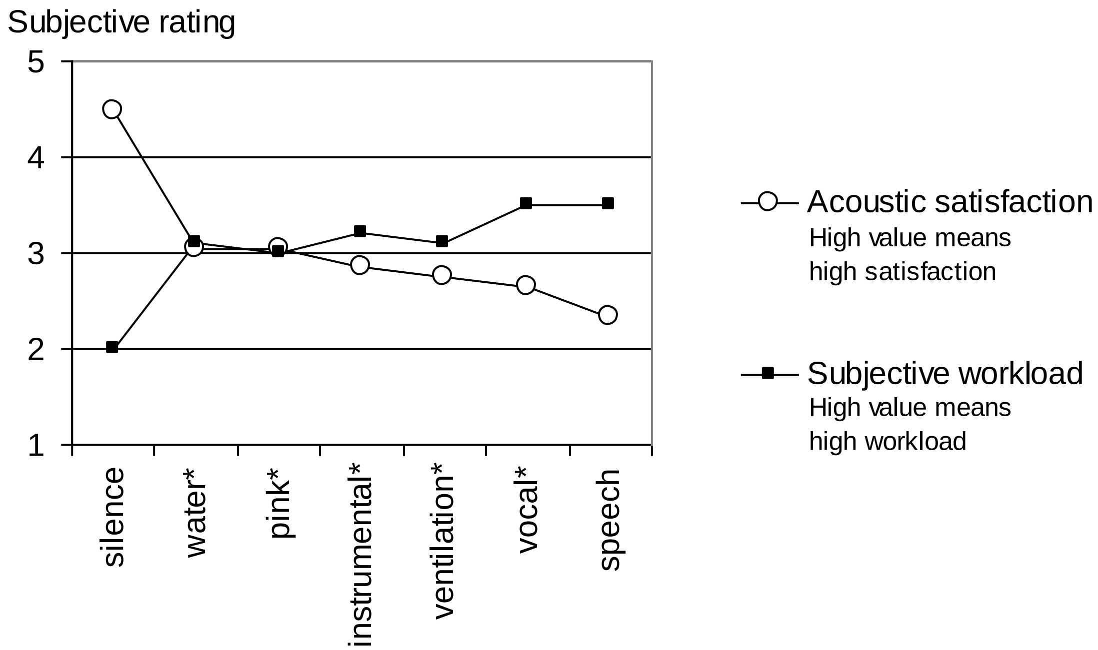


**Figure 4:** Acoustic satisfaction and subjective workload in the seven sound conditions.
Sounds with an asterisk (*) were played together with speech.

Acoustic satisfaction was significantly affected by the sound conditions ($F_{6,318}$=55, $p$<0.001, Figure 4). Silence was experienced as the most optimal condition, differing from all other conditions ($p$<0.001 for all, one-tailed). Masked speech conditions, however, produced higher ratings of acoustic satisfaction than unmasked speech (*p*≤.008 for all, one-tailed). The following differences were observed between different masked speech conditions: spring water sound was better than vocal music ($t(53)=3.8$, $p<0.001$, two-tailed) and filtered pink noise was better than either of the musical conditions, namely vocal music ($t(53)=3.5$, $p=0.002$, two-tailed) and instrumental music ($t(53)= 2.3$, $p=0.042$, two-tailed).

Subjective workload was also affected by sound conditions ($F_{6,318}=41$, $p<0.001$) and had a very similar pattern as acoustic satisfaction. Subjective workload was lowest in silence ($p<0.001$ for all comparisons to silence, one-tailed). Compared to speech, subjective workload was decreased with all other masking sounds except vocal music ($p<0.05$). This indicates that even though the condition with vocal music was experienced as more pleasant than speech, it was not experienced as an easier environment for performing tasks. Comparisons of masked speech conditions with each other further emphasized the negative experience of vocal music as it differed significantly from all other masked speech conditions ($p≤.015$, two-tailed). The use of instrumental music also resulted in higher subjective workload than the use of filtered pink noise ($p=0.026$, two-tailed).

The summary of statistically significant findings is presented in Table 2.

**Table 2:** A summary of findings and overall ranking of masking sounds. A "+" sign indicates that statistically significant improvements were observed in comparison to speech or some of the other masking sounds. A "-" sign indicates statistically significant decrements. Empty cell indicates that statistically significant differences were not found.

| | **Type of speech masking sound** | | | | |
|---|---|---|---|---|---|
| | water | pink | ventilation | instrumental | vocal |
| Comparison to speech | | | | | |
| Performance in serial recall task | + | | | | |
| Acoustic satisfaction | + | + | + | + | + |
| Subjective work load | + | + | + | + | |
| Comparisons between masking sounds | | | | | |
| Performance in serial recall task | + | | - | | - |
| Acoustic satisfaction | + | + | | - | - |
| Subjective work load | + | + | + | - | - |
| OVERALL RANKING ORDER | 1 | 2 | 3 | 4 | 5 |

## CONCLUSIONS

Carefully designed speech masking can reduce the negative effects of irrelevant speech on cognitive work performance and acoustic satisfaction. Vocal or instrumental music are not recommended to be used as a speech masking sound. The most common masking sounds, filtered pink noise and ventilation, are acceptable and also very practical alternatives. More advanced alternatives could be wide-band natural sounds, like the spring water sound, which was the most beneficial masking sound in this experiment. However, field experiments are required before natural sounds, such as spring water sound, can be widely recommended.

## ACKNOWLEDGEMENT

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# The effect of aircraft noise exposure on long-term memory: a report of the Bangkok Airport Study

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## INTRODUCTION

Previous studies suggest that aircraft noise exposure impairs cognitive performance such as reading, attention, and long-term memory (Evans et al. 1995, 1998; Haines et al. 2001a, 2001b; Hygge et al. 2002; Hiramatsu et al. 2003; Matsui et al. 2004; Stansfeld et al. 2005, 2010; Clark et al. 2006; Matheson et al. 2010). The Munich Airport Study (Evans et al. 1995, 1998; Hygge et al. 2002) was, for example, a longitudinal study conducted during the Munich Airport relocation to analyse the effect of aircraft noise exposure on cognitive function. The Munich Airport Study suggests that there might be a causal relationship between aircraft noise exposure and deficits in long-term memory and reading comprehension, and that these effects might be reversible.

Suvarnabhumi Airport in Bangkok, Thailand, officially opened in September 2006 to replace Don Muang Airport as the city's main international airport. The replacement of one inland international airport by another provided an opportunity for assessing the effect of aircraft noise exposure on cognitive function of primary school children. In order to investigate the effects of aircraft noise exposure on long-term memory, we measured the long-term memory of primary school children twice: before the opening of the new airport and 16 months after its opening.

## MATERIALS AND METHODS

### Airport and community

Figure 1 shows the map of Bangkok Metropolitan Area showing locations of the two airports. Don Muang Airport, which opened in 1914, was the first international airport in Thailand. It was located in the northern suburb of Bangkok and covered an area of 6.21 km$^2$ (Airport Authority of Thailand 1998). Initially, the surrounding areas comprised rice fields, but due to the rapid expansion of the urban area of Bangkok, people moved to the areas surrounding the airport, while the airport itself was also expanding with an increasing number of flights. This airport was reportedly used by nearly 80 airlines, more than 250,000,000 passengers in 160,000 flights, and 700,000 tons of cargo annually (Airport of Thailand Public Company Limited 2009a). Don Muang Airport was closed on 28 September 2006, and it became a facility for charter flights, military aircraft and civil aviation. However, it resumed service on 25 March 2007 to be used by domestic flights. It is estimated that there were approximately 90,000 flights in 2007 (Aeronautical Radio of Thailand 2009).

In order to create an aviation hub for Southeast Asia, the Royal Thai Government constructed a new international airport. The new airport, Suvarnabhumi Airport, is located in the eastern suburb of Bangkok, adjacent to Samutprakarn province, 25 km east of Bangkok. This inland airport covers approximately 32 km$^2$ (8,000 acres) of land (New Bangkok International Airport Co. Ltd. 2002) and has two runways, which can support 76 flights per hour, and can accommodate 45 million passengers and 3 million tons of cargo annually (Airport of Thailand Public Company Limited 2009b). In 2007, the number of flights passing through Suvarnabhumi Airport was recorded to be 270,283 (Aeronautical Radio of Thailand 2009).

Don Muang Airport is surrounded by town houses and apartments of middle-class families who moved to the area after the airport was opened. On the other hand, the area surrounding Suvarnabhumi Airport, previously well known for its fresh water fish farming, was used for agriculture; it consists of low- to middle-class families. A majority of these residents had lived there for 2–3 generations before the opening of the new airport.

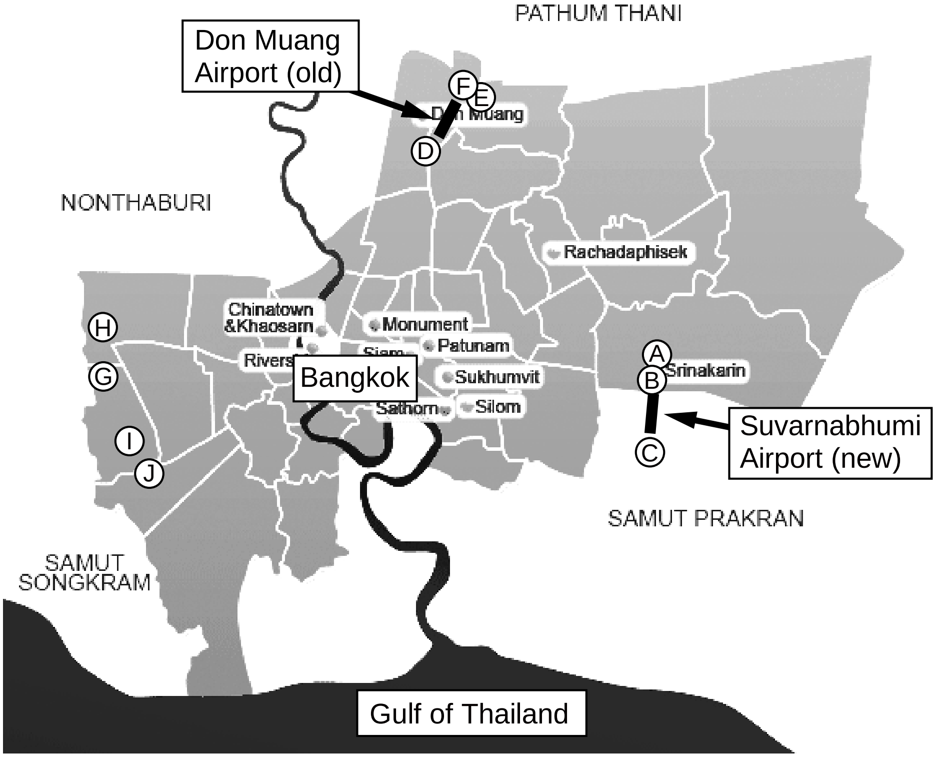


**Figure 1:** Map of Bangkok Metropolitan Area showing locations of two international airports and ten participating schools.

## Participants and aircraft noise exposure

Six primary schools from the area of NEF (Noise Exposure Forecast) 30–35 around the two airports were chosen for the study. Three private schools in Don Muang and 3 public schools in Suvarnabhumi participated in this study (see Figure 1). Primary school children studying in the fourth grade, aged 9–10 years, were recruited.

The control group comprised fourth grade students from 4 primary schools (3 public schools and 1 private school). All 4 schools were located in a western suburb of Bangkok where there was little aircraft noise exposure (see Figure 1).

In total, 684 primary school children studying in the fourth grade participated in this study: 205 from Suvarnabhumi (3 schools), 144 from Don Muang (3 schools), and 335 from the control area (4 schools).

Noise levels were measured twice at each school in Don Muang for a duration of 24 hours each: before the opening of the new airport (September 2006) and after its opening (April–May 2008). For each school in Suvarnabhumi, noise levels were measured after the opening of the new airport (March 2008) for a duration of 24 hours. The aircraft noise exposure level ($L_{Aeq,\ 24\ hours}$) at each school was calculated. Table 1 shows the aircraft noise exposure level at each school.

**Table 1:** Aircraft noise exposure level at each school

| Area | School | $L_{Aeq,\ 24\ hours}$ (dB) In 2006 | In 2008 |
|---|---|---|---|
| Suvarnabhumi | A (public) | Not available | 60 |
| | B (public) | | 62 |
| | C (public) | | 63 |
| Don Muang | D (private) | 73 | 61 |
| | E (private) | 63 | 54 |
| | F (private) | 63 | 54 |

## Memory test

Short-term and long-term memories were measured twice: the first test was conducted on 7–13 September 2006 before the opening of Suvarnabhumi Airport, and the second test was conducted on 7–11 January 2008, 16 months after its opening.

For the short-term memory test, the students were asked to memorize 15 disyllabic words, with each word being shown to them for 4 seconds. Next, a set of 30 words, 15 previously shown words and 15 new words, were shown to them. They were then asked to identify each word and mark '/' for a previously seen word and 'X' for a new word, on the answer sheet. The calculated percent difference between the 'right' and 'wrong' answers was considered as the memory score. The right answer was the number of previously seen words that the children remembered, while the wrong answer was 15 minus the number of new words that they could identify (Chaiyaporn 1977).

Long-term memory was assessed by a task (story C) adapted from the Child Memory Scale applied in the RANCH Study (Road traffic and aircraft noise exposure and children's cognition and health) (Stansfeld et al. 2005, 2010; Clark et al. 2006; Matheson et al. 2010). This task was translated into Thai language by one of the present authors (Nuchpongsai et al. 2009). The children were asked to read a short story in 50 seconds and write down everything they remembered of the story immediately. After 30 minutes of an interference activity such as drawing, playing games, puzzles, or intelligence quotient test, they were asked to write down again. The second writing was then scored with 1 point for each keyword similar to that of the guideline.

### Intelligence quotient (IQ) test

Intelligence was measured by using Progressive Matrices. Coloured Progressive Matrices are multiple choice tests of abstract reasoning, originally developed by John and Raven (Anastasi 1976). Thai versions of these tests developed by the Counseling Centre of Srinakharinwirot University were used in this study to adjust for the effect of intelligence factors on long-term memory scores. The test included 3 sets—sets A, AB, and B—consisting of 12 items. In each item, the children were asked to identify the missing segment required to complete a larger pattern from the choice of 6 pictures in 30 seconds.

For the noise-exposed group (Suvarnabhumi and Don Muang), this test was conducted 3 months after the first memory test. On the other hand, for the control group children, this test was conducted as an interference activity between the short-term and long-term memory tests.

### Statistical analysis

To investigate the effects of aircraft noise exposure on long-term memory, the differences in the long-term memory scores of the children in each group (Suvarnabhumi, Don Muang, and the control area) before and after the opening of the new airport were evaluated by using Wilcoxon signed rank test.

Further, the relationship between the change in the long-term memory scores due to the replacement of one inland international airport by another and the three groups (Suvarnabhumi, Don Muang, and the control area) was analyzed by using multiple logistic regression analysis. Two types of logistic regression models were used. The first model was unadjusted, while the second model was fully adjusted model. The fully adjusted model included gender, IQ, and the change in short-term memory scores, as explanatory variables. The IQ and the change in the short-term memory scores were included in the model as interval scales. In the fully adjusted model, the change in the short-term memory score was used as a measure of the change in motivation for learning.

All statistical analyses were performed by using SPSS software, version 17.0, at a $p<0.05$ (two-tailed) level of significance.

## RESULTS

The comparison of the long-term memory scores obtained before and after the opening of the new airport showed that the long-term memory scores of the children in Suvarnabhumi did not become significantly higher (Wilcoxon signed rank test, $p=0.182$), whereas those of the children in the control group became significantly higher (Wilcoxon signed rank test, $p<0.001$). The long-term memory scores of the children in Don Muang also became significantly higher (Wilcoxon signed rank test, $p<0.001$), but the increase was lesser than in the control group.

Figure 2 represents the change in the long-term memory scores in the three groups (Suvarnabhumi, Don Muang, and the control area). In this figure, the minimum, 25th percentile, median, 75th percentile, and maximum are shown for each group. As is evident from the figure, a significant difference was observed in the change in the long-term memory scores among the three groups (Kruskal-Wallis test, $p<0.001$). In the control group, approximately 77 % of the children showed an increase in their long-term memory score, while in Suvarnabhumi, only about 51 % showed an increase in their long-term memory score.

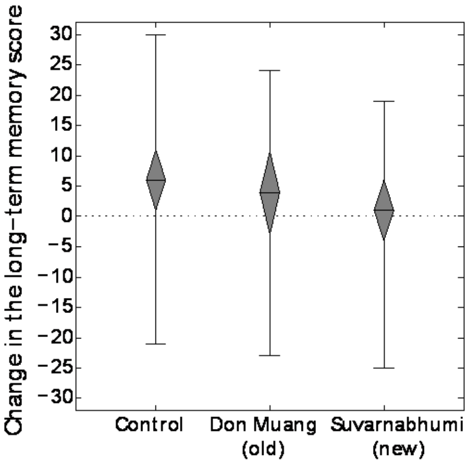


**Figure 2:** Change in the long-term memory score in the three groups. For each group, the minimum, 25th percentile, median, 75th percentile, and maximum are shown.

The relationship between the change in the long-term memory scores and the three groups was analysed by using multiple logistic regression analysis. In the analyses, the median value of the control group (6 points) was used as a cut-off point to convert it into a dichotomous variable for the logistic regression models.

Figure 3 illustrates the odds ratios with their 95% confidence intervals. In the figure, the asterisks indicate statistically significant odds ratios (*: p<0.05, ***: p<0.001). The unadjusted model showed that the children in Suvarnabhumi showed a significantly high odds ratio. The children in Don Muang also showed a significantly high odds ratio; however the odds ratio was lower than in Suvarnabhumi. As is evident from the figure, the fully adjusted model yielded similar results. Table 2 represents the results of the fully adjusted model. The relationship between the change in the long-term memory scores and the three groups was not affected by gender, IQ, or the change in the short-term memory score, the latter of which was used as a measure of the change in motivation for learning.

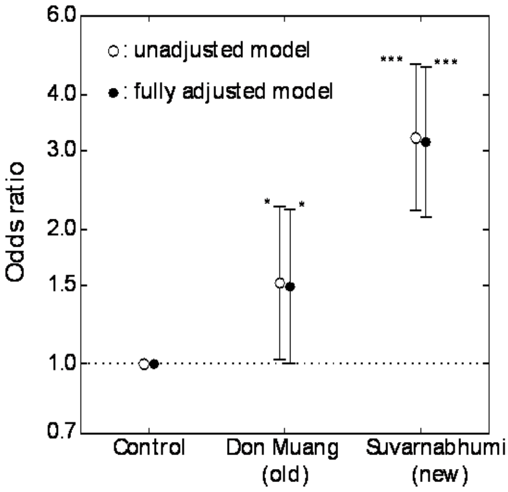


**Figure 3:** Relationship between odds ratios of long-term memory (less than 6 points) and the three groups. The asterisks indicate statistically significant odds ratios (*: p<0.05, ***: p<0.001).

**Table 2:** Results of the fully adjusted logistic regression model on long-term memory (less than 6 points)

| Factor | Category | N | Odds ratio | 95% CI | p value |
|---|---|---|---|---|---|
| Group | Control | 335 | 1 | | |
| | Don Muang (old) | 144 | 1.490 | 1.004–2.212 | 0.048 |
| | Suvarnabhumi (new) | 205 | 3.140 | 2.132–4.623 | <0.001 |
| Gender | Male | 350 | 1.131 | 0.826–1.547 | 0.443 |
| | Female | 334 | 1 | | |
| IQ | Interval scale | | 1.004 | 0.984–1.024 | 0.701 |
| Change in the short-term memory score (Change in motivation for learning) | Interval scale | | 1.002 | 0.997–1.006 | 0.410 |

## DISCUSSION

In summary, a significant association was found between the change in the long-term memory scores and the three groups (Suvarnabhumi, Don Muang, and the control area). In contrast with the long-term memory scores of the children in the control group, the long-term memory scores of the children in Suvarnabhumi did not become significantly higher, whereas those of the children in Don Muang became significantly higher, but to a lesser degree. Therefore, the increase in the long-term memory scores of the control group can be attributed to cognitive development in the children; moreover, it seems plausible that aircraft noise exposure might have hindered cognitive development in the children in Suvarnabhumi. The results of this longitudinal study strongly suggest that aircraft noise exposure might have adverse effects on long-term memory of primary school children.

The results of the present study, which suggest an effect of aircraft noise exposure on deficits in long-term memory, are consistent with previous findings from a longitudinal study, the Munich Airport Study (Evans et al. 1995; Hygge et al. 2002). In the Munich Airport Study, primary school children were instructed to read a text, and their memory was assessed by means of a free recall test on the following day. The results suggest that there might be a causal relationship between aircraft noise exposure and the deficits in long-term memory and that these effects might be reversible.

Several cross-sectional studies also suggest adverse effects of aircraft noise exposure on long-term memory (Hiramatsu et al. 2003; Matsui et al. 2004); for example, in the Okinawa Study (Hiramatsu et al. 2003), primary school children were asked to listen to a fictitious story and answer some questions asked on that day and the following day. The long-term memory tests used 15 common questions on the first and second days and an additional 5 questions asked on the second day. With regard to the additional 5 questions asked on the second day of the long-term memory test, a significant dose-response relationship was found between aircraft noise exposure and the deficits in long-term memory. The result obtained in the Okinawa Study suggests that chronic aircraft noise exposure lowers long-term memory of primary school children, which can hamper their learning ability.

Physiological mechanisms of how aircraft noise exposure affects children’s cognition have been suggested. For example, McEwen & Sapolsky (1995) state that stress affects cognition in a number of ways, when acting slowly via cortisol, which biphasically modulates synaptic plasticity for over hours and also produces longer-term changes in the dendritic structure that last for weeks. Moreover, prolonged exposure to stress leads to the loss of neurons, particularly in the hippocampus, which is an important component of brain and plays important roles in memory consolidation. This suggests that the deficits in long-term memory might be due to the effect of cortisol on the hippocampus. On the other hand, recent physiological studies suggest that alpha-melanocyte-stimulating hormone (alpha-MSH), which is produced by sleep disorders, has a similar effect on the hippocampal neurons (Ogawa et al. 2009). This implies that sleep disturbance due to aircraft noise exposure may be correlated with the deficits in long-term memory.

Stansfeld et al. (2010) also pointed out that sleep disturbance due to aircraft noise exposure might mediate the association of aircraft noise exposure and cognitive impairment in children. However, many previous studies, including the present study, have not differentiated between day or night time noise exposure. Further studies specifically designed to address the effects of night time noise exposure on long-term memory are required.

## CONCLUSION

A longitudinal study of the effects of aircraft noise exposure on long-term memory of primary school children was conducted in the area around the two airports in Bangkok, Thailand. As compared to the significant increase of long-term memory scores of the children in the control group, those of the children in Suvarnabhumi did not become significantly higher, whereas those of the children in Don Muang became significantly higher, but to a lesser degree. It seems reasonable to suppose that the increase in the long-term memory scores of the children in the control group was caused by their cognitive development and that aircraft noise exposure might have hindered the cognitive development of the children in Suvarnabhumi. We therefore conclude that aircraft noise exposure has adverse effects on long-term memory of primary school children.

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# A comparison of children's attention and cognitive function across noise conditions – a randomized controlled study

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## INTRODUCTION

There has been considerable amount of research in the past time into the impacts of noise on the performance of school children (Shield & Dockrell 2003). The studies have found indication of negative relations between noise exposure and delayed reading acquisition in young children (Evans & Lepore 1993). Most of these studies indicated that the effects of noise are due to chronic noise exposure rather than acute conditions during the testing phase. However, in some of studies, there is controversy of reading and chronic noise exposure, in which the significant relationship between noise level and reading score became non-significant after controlling socioeconomic status (Haines 2002).

Although, the acute noise impacts on cognitive function has been an object of study for a long time, there is still no adequate account for the circumstances in which noise will affect cognitive performance. The impacts of acute noise on reading performance are much more mixed. There are no effects of acute noise on mathematics performance but lower ability or hyperactive children might be risk for adverse impacts on mathematics (Slater 1968; Christie & Glickman 1980; Johansson 1983). Recently, three studies of children's reading and memory during acute noise (Hygge 2003; Hygge et al. 2003; Boman 2004), measures were also taken of attentional capacities, but attention was not found to mediate memory deficits created by noise. However, there are fewer studies of other cognitive process such as memory, attention, and reading in noise among children (Evans & Hygge 2007). The purpose of this study is to investigate the experimental simulated noise impacts on attention and on cognition of elementary school students under controlling various confounders.

## MATERIALS AND METHODS

### Background of choice of elementary school

The initial part of the study consisted in choosing the three schools in Ulsan, Korea according to environmental noise level, distance from traffic road, and distribution of socioeconomic status (SES) on the basis of data from Office of Education. From November 15th, 2010 to December 8th 2010, 268 students from three elementary schools (135 boys, 133 girls, and 10-12 years old) in Ulsan city, Republic of Korea were enrolled in this study. Demographic data on each the surveyed schools were obtained from a questionnaire for parents in order to control for socioeconomic factors in the analysis. This data consisted of medical history, recognition of residential noise, socioeconomic status.

### Noise surveys

Noise levels were measured outside and inside 3 schools, the main source to which the surveyed schools were exposed was road noise: school A was situated around three to four kilometers from airport and around 150 m from four-lane road on the suburb, school B was located near from four-lane road (around 50 m) on the outskirt, and school C was close to central Ulsan City situated residential area around 300 m from six-lane road. The average noise levels measured in each school and enrolled subjects are shown in Table 1.

**Table 1:** Noise levels and subjects of the surveyed schools

| School | Noise levels (LAeq/LCeq, dB) | | Subjects (Male/Female) |
|---|---|---|---|
| | Outside | Inside | |
| A | 54.2/64.3 | 46.0/58.5 | 50/39 |
| B | 58.5/67.8 | 44.0/61.3 | 43/44 |
| C | 62.8/66.3 | 47.9/57.0 | 42/50 |

### Cognitive performance testing in noise

### Tests

A battery of tests appropriate for fourth to sixth grade (10-12 years old) elementary school student was consisted. Comprehensive Attention Test (CAT), Korean Wechsler Intelligence Scale for Children (K-WISC), Children's Color Trail Test (CCTT), and Color and Word Test Children's version (STROOP) were performed in one of two noise conditions. All tests were conducted by trained nurse and computerized system.

- Comprehensive Attention Test (CAT) is composed of visual selective attention test, auditory selective attention test, divided attention test, and spatial working memory test. The visual selective attention test and auditory selective attention test were used to measure continuous performance ability. The divided attention test and spatial working memory test were used: attention capacity.
- Korean Wechsler Intelligence Scale for Children (K-WISC) is consisted of verbal and performance test. The verbal tests were composed of measuring verbal cognition ability: arithmetic and vocabulary. The performance tests were used: a speed of performance test designed to assess how quickly a child can perform mental operations. An estimated full scale IQ can be calculated by both verbal IQ and performance IQ.
- Color and Word Test Children's version (STROOP) is designed to assess not only the mental quickness and flexibility but also capacity of attention and cognitive inhibition.
- Children's Color Trail Test (CCTT) is composed of CCTT-1 and CCTT-2. CCTT-1 was used for measuring of perception trail ability and attention continuity. CCTT-2 was used: attention allocation and serial attention processing ability. Two tests were representative measures of complex information processing capacity.

Children were allocated into two noise conditions on the basis of the table of random sampling numbers. The subjects performed a series of attention and cognitive tests in background noise and in noisy condition. The noise conditions were as follows:

Noise level of test environment: 1) Control environment was given background noise (43.5-46.1 dB) as it was; 2) Experimental noisy environment was given additional 15-17 dB than background noise (60.8-62.8 dB). The noise was combined both road traffic noise and aircraft noise.

Before the tests, audiometric tests (pure tone audiometry and tympanometry) were carried out to evaluate the hearing threshold levels for all the children. Informed consents were approved by Institutional Review Board in Ulsan University Hospital.

### Data analysis

Chi-square tests and analysis of variances were carried out to assess the difference between education level, income and school for categorical and continuous variables, respectively. General linear model were conducted to analyze the association between noise and attention and cognitive functions after controlling SES.

## RESULTS

Demographic results of this study were summarized in Table 2. On the whole, the paternal education level and monthly income of school C was higher than school A and B. There were significant differences of SES between three schools ($X^2$ = 65.0, p<0.001 on paternal educational levels; $X^2$ = 33.0, p<0.001 on monthly incomes). The hearing levels of enrolled children were under the reference value (0~25 dBHL, average of hearing level 0.5, 1, 2 kHz).

**Table 2:** Demographic characteristics of the participants

| | School | | | | | | Total | | p-value |
|---|---|---|---|---|---|---|---|---|---|
| | A | | B | | C | | | | |
| | n | % | n | % | n | % | n | % | |
| Sex | | | | | | | | | |
| Boys | 50 | 37.0 | 43 | 31.9 | 42 | 31.1 | 135 | 100 | $X^2$=2.052 |
| Girls | 39 | 29.3 | 44 | 33.1 | 50 | 37.6 | 133 | 100 | *p*=0.358 |
| Developmental history | | | | | | | | | |
| Low birth weight | 5 | 5.6 | 4 | 4.7 | 4 | 4.3 | 13 | 4.9 | .875 |
| Premature baby | 5 | 5.6 | 3 | 3.5 | 5 | 5.4 | 13 | 4.9 | .775 |
| Paternal education | | | | | | | | | |
| ~8 yr | 4 | 4.7 | 1 | 1.2 | 0 | 0 | 5 | 1.9 | $X^2$=65.046 |
| 9~12 yr | 60 | 69.8 | 61 | 71.8 | 24 | 26.1 | 145 | 55.1 | *p*<0.01 |
| 13~14 yr | 9 | 10.5 | 8 | 9.4 | 13 | 14.1 | 30 | 11.4 | |
| 14~16 yr | 12 | 14.0 | 15 | 17.6 | 50 | 54.3 | 77 | 29.3 | |
| 17 yr ~ | 1 | 1.2 | 0 | 0 | 5 | 5.4 | 6 | 2.3 | |
| Monthly income($) | | | | | | | | | |
| ~2,000 | 17 | 19.1 | 26 | 30.6 | 8 | 8.7 | 51 | 19.2 | $X^2$=33.000 |
| 2,000~3,000 | 29 | 32.6 | 24 | 28.2 | 17 | 18.5 | 70 | 26.3 | *p*<0.01 |
| 3,000~4,000 | 27 | 30.3 | 16 | 18.8 | 23 | 25.0 | 66 | 24.8 | |
| 4,000~5,000 | 9 | 10.1 | 9 | 10.6 | 22 | 23.9 | 40 | 15.0 | |
| 5,000~ | 7 | 7.9 | 10 | 11.8 | 22 | 23.9 | 39 | 14.7 | |

The comparisons of attention and cognitive performance tests were summarized as follows in Table 3 to 5. There were significant difference between Control (C) and Noisy group (N) on Comprehensive Attention Test (CAT), Korean Wechsler Intelligence Scale for Children (K-WISC), Children's Color Trail Test (CCTT) and Color and Word Test Children's version (STROOP).

After adjusting for socio-demographic covariates, general linear models showed that a significant differences existed between experimental simulated noise and CPT scores: 1) the response time on the auditory selective attention test (85.19 for C group vs. 91.51 for N group, p=0.007), 2) the omission error and response time on the divided attention test (92.98 for C group vs. 86.01 for N group, p=0.034; 98.84 for C group vs. 104.72 for N group, p=0.047; respectively), and 3) the forward memory span and forward correct response on the spatial working memory test (96.80 for C group vs. 91.42 for N group, p=0.045; 95.21 for C group vs. 89.23 for N group, p=0.020; respectively).

**Table 3:** Differences of the continuous performance test (CPT) between control and noise groups adjusting for sex, grade, monthly income, and paternal education

| CPT | Group | | | | p-value |
|---|---|---|---|---|---|
| | Control group | | Noise group | | |
| | Mean | SE | Mean | SE | |
| Visual selective attention test | | | | | |
| Commission error | 90.40 | 2.25 | 92.14 | 2.61 | .617 |
| Omission error | 85.63 | 1.96 | 82.94 | 2.28 | .375 |
| Response time | 92.37 | 1.25 | 90.73 | 1.46 | .400 |
| Response time-SD | 87.23 | 2.05 | 84.46 | 2.38 | .381 |
| Auditory selective attention test | | | | | |
| Commission error | 99.51 | 1.65 | 100.35 | 1.91 | .743 |
| Omission error | 94.55 | 1.43 | 93.87 | 1.65 | .757 |
| Response time | 85.19 | 1.50 | 91.51 | 1.74 | .007 |
| Response time-SD | 92.01 | 1.57 | 93.04 | 1.82 | .671 |
| Divided attention test | | | | | |
| Commission error | 71.49 | 2.55 | 67.23 | 2.95 | .279 |
| Omission error | 92.98 | 2.12 | 86.01 | 2.46 | .034 |
| Response time | 98.84 | 1.91 | 104.72 | 2.22 | .047 |
| Response time-SD | 97.20 | 1.84 | 96.46 | 2.13 | .794 |
| Spatial working memory test | | | | | |
| Forward memory span | 96.80 | 1.73 | 91.42 | 2.01 | .045 |
| Forward correct response | 95.21 | 1.66 | 89.23 | 1.92 | .020 |
| Backward memory span | 89.84 | 2.46 | 85.27 | 2.85 | .229 |
| Backward correct response | 89.80 | 2.09 | 85.43 | 2.43 | .176 |

In KWISC, both the verbal IQ (arithmetic and vocabulary) and performance IQ (picture arrangement) existed significantly difference with experimental simulated noise except for block design as shown in Table 4. Vision-play coordination performance was not affected by experimental simulated noise condition. In brief, full-scale IQ scores (116.71 for C vs. 109.68 for N, p<0.001) and verbal IQ scores were negatively associated with the existence of experimental noise.

**Table 4:** Differences of the IQ Scores between control and noise groups adjusting for sex, grade, monthly income, and paternal education

| KWISC | Group | | | | p-value |
|---|---|---|---|---|---|
| | Control group | | Noise group | | |
| | Mean | SE | Mean | SE | |
| Arithmetic | 12.11 | 0.18 | 11.30 | 0.22 | .006 |
| Vocabulary | 13.37 | 0.33 | 11.80 | 0.38 | .002 |
| Block design | 14.01 | 0.34 | 13.50 | 0.40 | .346 |
| Picture arrangement | 11.59 | 0.29 | 9.99 | 0.34 | .001 |
| Full scale IQ | 116.54 | 1.11 | 110.04 | 1.29 | <.001 |

The analyzed results of the STROOP test and CCTT tests were shown as Table 5. These tests used to assess frontal lobe function such as attention, cognitive inhibition, and mental operation speed.

On the STROOP test, the word score was significantly affected by experimental noise (50.82 for C group vs. 48.22 for N group, p=0.030). However, the differences of reading ability between C group and N group turned out to be board line statistical significance after adjusting for sex, grade, monthly income, and paternal education (50.29 for C group vs. 48.03 for N group, p=0.056). In the CCTT tests, the CCTT-1 total time of noise group was significantly delayed (20.51 for C group vs. 22.50 for N group, p=0.021) than control group.

**Table 5:** Differences of the STROOP and CCTT Scores between control and noise groups adjusting for sex, grade, monthly income, and paternal education

| | Group | | | | p-value |
|---|---|---|---|---|---|
| | Control group | | Noise group | | |
| | Mean | S.E. | Mean | S.E. | |
| STROOP test | | | | | |
| Word score | 50.29 | 0.76 | 48.03 | 0.88 | .056 |
| Color score | 50.35 | 0.95 | 49.93 | 1.11 | .779 |
| Color-word score | 49.20 | 0.93 | 49.06 | 1.08 | .921 |
| Interference score | 48.36 | 0.98 | 48.65 | 1.15 | .851 |
| CCTT | | | | | |
| CCTT-1 total time(T score) | 47.73 | 1.08 | 43.94 | 1.31 | .030 |
| CCTT-2 total time(T score) | 48.63 | 1.02 | 47.26 | 1.24 | .400 |
| Interference score(T score) | 52.22 | 3.01 | 56.76 | 3.64 | .343 |

## DISCUSSION

The objective of this was to investigate the experimental simulated noise (15~17 dB higher than background noise) impacts on attention and cognition of elementary school students. There was statistically significant difference in socioeconomic status (paternal education level and monthly income) among three schools.

The comparisons of noise levels and a battery of test results showed that experimental noise have a detrimental impact upon children's attention and cognitive performance after controlling socioeconomic status. In CAT scores, differences were found that 1) the response time on the auditory selective attention test, 2) the omission error and response time on the divided attention test, and 3) the forward memory span and forward correct response on the spatial working memory test. A possible explanation is that presentation of experimental noise produced observable increases in child distraction and off-task time (Wyon 1970). Our results of visual selective attention tests were not affected by simulated noise whereas Glenn et al. (1978), who found performance on visual attention task was degraded. In KWISC tests, the full-scale IQ scores and verbal IQ scores were negatively associated with the existence of experimental noise. This finding was closely consistent with the results of the controlled experimental testing which found that classroom babble had a detrimental effect upon children's performance of verbal and non-verbal tasks. Moreover, environmental noise had more of an impact upon the older children than younger ones (Shield & Dockrell 2008).

The word score in the STROOP test and CCTT-1 total time of noise group were significantly affected by experimental noise. Both the STROOP test and the CCTT tests represent that reading speed were significantly affected by the experimental simulated noise. These results correspond with the results of earlier studies which reported that negative relationship between reading and noise (Hygge et al. 2002; Stansfeld et al. 2003).

## CONCLUSION

Taken together the results provide that the noise affects attention and cognitive functions such as CAT, KWISC, CCTT, and STROOP. Moreover, the impacts were consistent after controlling demographic confounders. The findings here suggest that noise (above 15~17 dB higher than background) is hazardous to attention and cognitive performance on elementary school students. Further study is needed to elucidate the positive and negative effect for cognitive function in terms of the noise level.

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# The effects of aircraft noise on the auditory language processing abilities of English First Language primary school learners

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## INTRODUCTION

Auditory processing difficulties may cause scholastic difficulties (Cacace & McFarland 1998) and research has shown that chronic noise exposure can have a negative effect on some auditory processing skills (Maxwell & Evans 2000) which, in turn, may impact on children's scholastic performance. However there has been very little research on the effect of long term aircraft noise exposure on the auditory processing skills of children when hearing thresholds are within normal limits. Airports are notoriously noisy environments and already in 1974, Crook & Langdon demonstrated that noise levels within schools near airports in London peaked at or above 70 dBA with at least one out of every four flights. Therefore, this study sought to investigate the effects of long term aircraft noise exposure on the auditory language processing abilities of English First Language primary school learners attending schools in Durban, South Africa since processing problems may manifest as difficulties with reading, spelling or other learning problems.

### Auditory Language Processing

Auditory Language Processing (ALP) occurs beyond the peripheral auditory system and requires an intact peripheral auditory system to transmit the signal along the auditory pathway to the brain where it passes from the auditory nerve to the cochlear nucleus (CN), then continues to the superior olivary complex, through to the lateral lemniscus to the inferior colliculus. The signal continues through to the medial geniculate body of the thalamus and then reaches the auditory cortex (Phillips 2007; Katz et al. 1992) where it is processed. The processing of language is the ability to attach meaning to an auditory signal using linguistic knowledge and tends to occur in the temporal lobe, more specifically Heschel's Gyrus, Angular Gyrus as well as Broca's area. Primary, secondary and tertiary zones of the brain progressively attach meaning to the auditory signal (Richard 2001). Poldrack et al. (2001) investigated the neural basis of auditory processing in comparison to phonological processing and they found that a subset of the left inferior frontal regions involved in phonological processing in reading are also sensitive to acoustic features within the range of comprehensible speech. Thus, we can see that there is an overlap in the processing of auditory and language signals and cannot always be distinguished as separate entities.

### Signs and symptoms of an auditory language disorder

An auditory language processing disorder is characterized by difficulties in the interpretation of acoustic signals. The signs and symptoms can vary considerably, depending on the degree of the disorder and the individual child affected (Geffner & Ross-Swain 2007). Auditory processing problems can manifest in several ways, where, in some instances, a person with an auditory language processing disorder

(ALPD) is aware of his/her difficulty with listening and understanding signals that is exacerbated by some situations or environments, such as in noise. However, with others, the actual difficulties that arise from ALPD are more subtle, such as disturbances with learning, language, spelling, reading, socializing and problem solving skills (Bellis 2002). Bellis (2007) estimated that half of all children identified with a learning disorder exhibit an auditory processing disorder and auditory processing disorders are estimated to occur in 2–3 % of children (Martin & Clark 2003). Therefore, children in the vicinity of airports may have an even larger chance of developing an ALPD.

### Noise causing cognitive, psychological and health problems

Aircraft and road traffic noise can impact on cognitive tasks as demonstrated in a study in the Netherlands, Spain and the United Kingdom by Stansfeld et al. (2005) which showed that chronic aircraft and road traffic noise could impair cognitive development in children, specifically reading comprehension. Similarly, in Los Angeles, it was shown that there were approximately 300 over-flights daily peak sound readings in these schools were 95 dBA. This study showed that the children in the noisy schools, compared to the matched quieter schools were more likely to give up before time, more likely to fail on a cognitive task, and more likely to have higher blood pressure (Cohen et al. 1980). Therefore, these studies show that noise can have adverse effects on learning and it appears necessary to look specifically at AP effects as there appears to be a dearth of literature in this aspect.

### Classroom acoustics

Environmental and aircraft noise can contribute to a poor signal to noise ratio and poor listening conditions within classrooms, where, as Palmer (1997) points out, children can spend up to 45 % of their school day engaged in listening activities. In South Africa there are no national standards for classroom acoustics, simply noise level recommendations. Typical school buildings and classroom layouts vary between countries in ways that are often related to material resources. Many schools in South Africa have been described as large, dilapidated and unwieldy classrooms with limited recourses. In some schools, learning takes place in prefabricated buildings with very thin walls; while other schools, although made of brick buildings, have poor acoustics such as thin windows and doors, and limited posters and carpets to absorb the sounds which does not at all help to achieve an acceptable S/N ratio for the children to learn. Although the layouts and environments are important, it is necessary to make accommodations depending on budget and recourses (Higgins et al. 2005), which is a common issue in South Africa. The promotion of health is what nations should aspire to, rather than solely provide treatment, such as therapy. Consequently, it has been proposed that causative variables can be identified and accommodated by suggesting preventative implementations improve the S/N ratio in the classroom, and assist in preventing ALPDs (Levi 2005).

Therefore, because of the recognized effects of noise on learning and the high levels of noise near airports, it became apparent to study the effect of noise on particular aspects of auditory processing to better understand the impact of noise on these auditory processing skills since compromised auditory language processing skills can have an impact on classroom learning.

## METHODOLGY

The aim of this study was to investigate the auditory language processing abilities of English First Language (EFL) learners who attend aircraft-noise-exposed schools and learners who attend non-aircraft-noise-exposed schools in Durban, South Africa.

### Context of the study

The results shared here form part of a larger Master of Arts in Audiology project. It is also related to the RANCH-SA (Road Traffic and Aircraft Noise and Children's Cognition and Health-South Africa) project conducted in the Departments of Psychology, Education (Geography discipline) and Speech Pathology and Audiology at the University of the Witwatersrand.

### Research design

The current study utilized a non-experimental, cross sectional and descriptive design, as well as a post-hoc design.

### Ethical considerations

Permission to conduct this study was granted by the University of the Witwatersrand's Human Ethics Research Committee (protocol number 2008ECE94). Information sheets and consent forms were sent to the parents or caregivers of the learners, as well as verbal assent was obtained from the learners themselves. Participants who failed the hearing screening or who were identified with auditory processing deficits during the data collection phase were referred for further assessment. Teachers were also provided with strategies to implement in the classroom to help these learners. Confidentiality of the results in the write-up of the study was assured.

### Participants

In order to investigate the auditory processing abilities of children exposed to aircraft noise, participants from four schools were grouped according to whether they attended the noisier schools or the quieter schools. Learners from two schools exposed to high intensities of aircraft noise formed the one group while the other group consisted of learners from two schools exposed to considerably less noise, not located in close proximity to the airport. The noisy schools were broadly matched to the quieter schools on the basis of socio-demographic characteristics to reduce subject variability between schools. Criteria for participation in the study included continued attendance at the school from grade one and hearing levels within normal limits when screened by an audiologist. In addition, only the learners from grade six through to grade seven were eligible to participate in this study in order to see the long term effects of chronic airport noise exposure. Only English First Language (EFL) learners were included in this study as the tests are standardized on first language English speaking children and to preclude any reliability and validity issues from second language English speakers who attend the four selected schools. Learners with pre-established learning difficulties were excluded from this study.

### Auditory processing measurement instruments

Verbal working memory, auditory discrimination, phonological awareness and phonological memory are important skills for academic learning. These areas were thus selected to be the focus of this research.

This study utilized the following subtests to investigate children's auditory processing abilities:

- Subtests of the Test of Auditory Processing Skills (TAPS) (Verbal Working Memory and Auditory Discrimination) (Gardner 1985)
- Subtests of the Phonological Assessment Battery (PhAB) (Phonological Awareness) (Frederickson et al. 1998)
- The Dollaghan and Campbell Non-word Repetition Task (Phonological Memory) (Dollaghan & Campbell 1998).

The TAPS is an assessment tool developed to measure a child's functioning in various areas of auditory perception and include auditory discrimination, auditory number memory-reversed and auditory sentence memory. The Rhyme and alliteration tests are subtests of the PhAB which was designed to asses phonological processing. The Dollaghan and Campbell Non-word Repetition Task involves 16 non words, ranging from CVC's to CVCVCVCVC's. The aim of the non-word repetition task is to assess phonological memory in a non-biased manner with regard to language proficiency and vocabulary.

### Procedure and protocol

1. Pilot study

The auditory language processing instruments (TAPS, PhAB, non-word repetition task) underwent a pilot study at a public sector school which was demographically matched to the sample schools. All the tests proved reliable for the population being tested, apart from the spoonerism test which was, therefore, excluded from the testing procedure. No modifications were necessary on the other tests.

2. Data collection

Hearing screening:

Hearing screening included otoscopy (Heinz mini otoscope), tympanometry (GSI 38 tympanometer) and screening pure tone audiometry (GSI screening audiometer). Cut-off screening levels were at 20 dB HL at 500 Hz, 1kHz, 2kHz and 4kHz. Learners who failed in audiometric screening (two or more frequencies in at least one ear), in tympanometry or otoscopy were referred for further assessment and were excluded from further auditory processing assessment.

Noise measurements:

A SVAN 955 type one sound level meter was used to measure noise. The average sound levels (LEQ), as well as maximum and minimum sound levels were recorded.

Auditory language processing assessment:

Tests were conducted with the children on an individual basis throughout the school day by two audiologists.

## Data analysis

These research data were scored and analyzed with various methods to ensure accurate interpretation of the individual tests. Various tests, such as Pearson's chi-squared tests, Fisher's exact test were used on the auditory discrimination, auditory number memory and auditory sentence memory tests, and three-way ANOVA were used on the non-word repetition task, rhyme and alliteration subtests, while descriptive methods were also utilized with the means of tables and figures. In order to compare the significance of the auditory discrimination, auditory number memory and auditory sentence memory, the strength of association (Cramer's V test) was calculated.

## RESULTS

The results are summarized hereafter.

**Table 1:** Noise levels and hearing screening results

| | School A (noisier) | School B (noisier) | School C (quieter) | School D (quieter) |
|---|---|---|---|---|
| **Noise levels** | 69.9 dBA | 63.5 dBA | 55.3 dBA | 54.4 dBA |
| **Percentage of learners who failed the hearing screening** | 27.9 % | 27.1 % | 5 % | 23.4 % |

The results of the chi-squared and Fisher's exact test can be observed at the p<0.05 level, as well as the strength of the positive association (see Table 2).

**Table 2:** Summary of the chi-squared tests, Fisher's exact test and Cramer's V tests conducted for the auditory discrimination, auditory number memory, and auditory sentence memory subtests

| **Relationship** | **Auditory test** | | | | | |
|---|---|---|---|---|---|---|
| | **Auditory discrimination** | | **Auditory sentence memory** | | **Auditory number memory** | |
| | ***Calculated $X^2$ (p-value) with Cramer's V*** | ***Scores of ≥12 years in noisy vs. quieter schools*** | ***Calculated $X^2$ (p-value) with Cramer's V*** | ***Scores of ≥12 years in noisy vs. quieter schools*** | ***Calculated $X^2$ (p-value) with Cramer's V*** | ***Scores of ≥12 years in noisy vs. quieter schools*** |
| **Noisy vs. quiet schools** | 2.03 (0.155) | 51 % in noisy versus 63 % in quieter | 15.1 ** (<0.001) 0.34 moderate association | 54 % in noisy versus 85 % in quieter | 10.8 ** (0.001) 0.29 moderate association | 25 % in noisy versus 53 % in quieter |
| **Grade 6: Noisy vs. quiet schools** | 5.38 ** (0.020) 0.30 moderate association | 11 % in noisy versus 38 % in quieter | 13.9 ** (<0.001) 0.49 relatively strong association | 33 % in noisy versus 81 % in quieter | 4.61 (0.032)* | 0 % in noisy versus 16 % in quieter |
| **Grade 7: Noisy vs. quiet schools** | 0.19 (0.666) | 82 % in noisy versus 86 % in quieter | 3.66 (0.056) | 71 % in noisy versus 89 % in quieter | 13.7 ** (<0.001) 0.44 relatively strong association | 44 % in noisy versus 86 % in quieter |

* Fisher's exact test was not significant at p= 0.05

** Significant results (quieter schools performed better than noisy schools)

The overall effect of noise on the non-word repetition, rhyme and alliteration task can be observed from ANOVA measures (see Table 3).

**Table 3:** The results of the analysis of variance analyzing the non-word repetition task, rhyme and alliteration tests at the p<0.05 level

| **Relationship** | **Auditory test** | | |
|---|---|---|---|
| | **Non word repetition** | **rhyme tests** | **alliteration test** |
| | ***Calculated ANOVA (p-value)*** | ***Calculated ANOVA (p-value)*** | ***Calculated ANOVA (p-value)*** |
| Noisy vs. quiet schools | p=0.020 | p < 0.001 | p < 0.001 |

DISCUSSION

From these results, it appears evident that aircraft noise affects the auditory language processing skills investigated in this study. Hindrances of auditory processing abilities, can affect multiple areas, such as learning, literacy, numeracy, and in turn, social and psychological factors.

According to Wepman (1960), most auditory discrimination skills should be developed by eight years of age, or by the end of grade three. Learners in this study were already in grade six and seven and appeared to show auditory discrimination difficulties. A weakness in auditory discrimination skills can be problematic as it can hamper educational development, such as with further learning: if learners struggle to distinguish sounds, they may have difficulty learning the phonemes which is an important aspect of reading (Wepman 1960).

The reduced scores in the rhyme and alliteration tasks may also suggest that the learners in this study may be at risk for reading difficulties since, as Bryant et al. in Lonigam et al. (2000) found, there is a link between learning and literacy development as it has been found that the sensitivity to rhyme leads to awareness of phonemes, which in turn is related to reading.

Similarly, the decreased performance in areas such as auditory memory may impinge on learning during class as the learner may find it difficult to retain the information presented in class and may also have difficulties with sequencing. Therefore, learning in a noisy environment can hinder the development of ALP skills, and could result in academic difficulties which may also have social, psychological and emotional consequences if the learner struggles at school.

The importance of working memory is further discussed by Lee et al. (2004) when they describe how working memory contributes to early arithmetic performance and mathematical development. Also, the reduced number memory and sentence memory scores (related to working memory) observed in this study, can further affect mathematical development. In South Africa, a country where there are low levels of reading and numeracy (Taylor et al. 2003), the addition of noise to an already disadvantaged community may again intensify this problem.

South Africa already feels the burden of health issues within a context of poverty. It is reported that there are approximately 5.3 million people infected by HIV/AIDS in South Africa (Lubbe 2008). HIV/AIDS can place children at a risk for chronic otitis media, and thus fluctuating hearing loss, and may cause neural hearing difficulties too (Larsen in Khoza 2009). More so, the Committee of Inquiry into a Comprehensive Social Security System for South Africa found that between 45 and 55 % of all South Africans live in poverty (Martin & Rosa 2002). Therefore, it would suggest that placing vulnerable learners who attend noisy schools may be at even greater risk for ALPD since the noise may compound the other matters.

## CONCLUSION

Auditory language processing difficulties have been identified in both noisy and quiet schools although more problems were identified in noisy schools. The ALP data from aircraft noise exposed schools can be extrapolated to schools exposed to other types of excessive and continuous noise which suggest some recommendations for education. One of the recommendations could suggest the need to motivate for the provision of speech-language therapy and audiology services within mainstream schools, as well as informing educators about auditory language processing difficulties. Similarly, it would be beneficial to improve the acoustic design of new classrooms to enhance the listening of learners as well as the sound treatment of existing classrooms since, by adjusting some measures of the existing design in the classroom, classroom acoustics can be improved (Edwards 2002). Lastly, the results of this research aim to motivate for a change of legislation for more appropriate specifications with regard to zoning of schools away from noisy areas and the standardization of acceptable noise levels. In South Africa, a country with developmental challenges, where successful education is seen as a hope for future development, addressing factors which can compound learning difficulties, such as auditory language processing difficulties brought on by environmental noise, may provide opportunities for successful learning.

However, despite these recommendations, it is important to heed the advice from Higgins et al. (2005) when they suggest that in a changing world, no design solution will last forever, and thus, on-going research and involvement is always necessary for on-going support and change.

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# Overview of research into sleep disturbance due to noise in the last three years

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## INTRODUCTION

It is well established that noise can disturb sleep and if this disturbance is severe and frequent enough it can lead to significant fragmentation and sleep deprivation which seriously affects our physical and mental health. In the early days of modern sleep research there was a considerable emphasis on understanding the importance of the type and structure of sleep in terms of its electro-physiologically defined sleep stages and the nature of recovery sleep following sleep deprivation (Dement & Greenberg 1966). However, it is unclear how the well documented deleterious effects of these early sleep deprivation studies can be applied to environmental noise disturbed sleep (Zaharna & Guilleminault 2010) as the typical level of environmental noise is usually not severe enough to produce the same degree of sleep deprivation and/or fragmentation as the early experimental studies were designed to provoke significant outcomes.

Nonetheless, it has been clearly established that we can have autonomic responses to noise at low levels that do not produce wakefulness (Muzet 2007), as well as responses that could be described as minor fragmentation which includes shifts to lighter sleep stages, movement and/or brief wakefulness which are frequently associated with limb and body movement (Ollerhead et al. 1992). In addition, there is clear evidence that night-time noise has been associated with cardiovascular disease (Jarup et al. 2008) and stroke in the elderly (Sorensen et al. 2011. What is lacking is evidence of a clear pathway that directly links noise (at ecological levels) and disturbed sleep with cardiovascular disease.

One factor that makes it difficult to determine clear dose response relationships for these autonomic and minor sleep fragmentation responses to noise is that they also occur naturally in the absence of noise and any other obvious external agent. The dilemma has been how to establish an acceptable point at which the additional reactions to noise results in clear negative health endpoints (Brink et al. 2009). Adding to the dilemma is the large number of uncontrolled non-auditory factors e.g. annoyance, work and psychosocial stress, and personal characteristics e.g. noise sensitivity, that are known to affect our sleep and reaction to noise.

## TRANSPORTATION NOISE

The last 3 years has seen continued interest in the effect of transportation noise on sleep. This has been driven mainly by the continued and planned expansion of aviation and high speed trains, which is considered to develop faster than noise suppressing technology. The future predictions for air-travel volumes indicate considerable growth and increased noise which outweighs the reductions due to quieter jet aircraft and other noise mitigation measures (Girvin 2009). The main focus of research into noise disturbed sleep over the last couple of decades has been in Europe. This has in part been a consequence of the realization of the European Noise Directive (END) which required governments to provide detailed noise maps of urban conglomerations in member states and then to produce Action Plans on the basis of these Maps, which should outline how citizens living in the particularly noisy areas in the Maps are going to gain relief. This implies the need for quantification of the effectiveness of practical intervention measures that may be applied.

Over the last three years the FAA (US) have set about developing a 'Research Roadmap' for future work into 'Advancing Aircraft Noise Impacts Research' with a main emphasis on sleep disturbance and annoyance caused by aircraft noise (Girvin 2009). The essential aim of such research is to provide the best evidence for the formulation of legislation to regulate noise that has the potential to harm citizens. The research development process for the Noise Research Roadmap started with the formation of two small groups of experts and stakeholders in sleep disturbance and annoyance generation. This focus was broadened in 2009 at Euronoise in Edinburgh and Internoise in Ottawa where an International Forum on Aircraft Noise Impacts was held and further developed with Annual Research Roadmap Meetings in Washington in 2010 & 2011.

The differences in noise-induced sleep disturbance due to different transportation mode (air, road and rail singularly and in combinations) has received considerable debate and conjecture in the literature. A recent laboratory based study (Basner et al. 2011) has shed considerable light on the topic. They studied 72 subjects (32 male) for 11 consecutive nights with 0, 40, 80 and 120 noise events employed in a balanced design, in terms of number of noise events, maximum sound pressure level and equivalent noise load. The results showed that road traffic caused the most obvious changes in sleep structure and continuity whereas air and rail was considered more disturbing subjectively. This was attributed to road traffic noise events being too short to be consciously perceived by the subjects that had awoken in response to the event. The results also showed that while subjective annoyance was greater for aircraft noise, cortical and cardiac responses during sleep were lower for air compared to road and rail traffic. A fascinating result was that most (>90 %) of the noise induced awakenings merely replaced awakenings that would have occurred spontaneously, which helped to preserve sleep continuity and structure despite the noise. This suggests that within limits there is some homeostatic mechanism for internal monitoring and control of waking arousals (or maintaining sleep) that are allowed during each night's sleep.

## THE WHO – EUROPE

The WHO – Europe have continued to be instrumental in driving the environmental health agenda in Europe and published the Night Noise Guidelines (NNG 2009) which summarize the deliberations of many experts and provide a clear and simple guide for planners and regulators. The NNG summarize the relationship between night noise and health effects into four ranges of continuous outside sound level at night (Ln):

**<30 dB** – no substantial biological effects should normally be expected;
**30-40 dB** – primary effects on sleep start to emerge and adverse effects in vulnerable groups;
**40-55 dB** – sharp increase in adverse health effects while vulnerable groups become severely affected;
**>55 dB** – adverse health effects occur frequently with high percentage of the population annoyed.

More recently WHO – Europe (2011) have reported on the burden of disease as a result of the growing concern of the public, environmental health agencies and policy makers in Europe, in terms of disability-adjusted life-years (DALYs) lost due to environmental noise. The findings suggest that sleep disturbance, due mainly to road traffic noise, constitutes the heaviest burden followed by annoyance which account for 903,000 and 587,000 DALYs respectively. The other factors associated with environmental noise are ischaemic heart disease (61,000 DALYs), cognitive impairment in children (45,000 DALYs) and tinnitus (22,000 DALYs). The report concludes with the estimate that at least one million healthy life years are lost every year from traffic related noise in Western Europe.

## WIND-TURBINE AND HOSPITAL NOISE

There has been a growing interest in the negative health effects, particularly on sleep and annoyance, associated with other environmental noise producers particularly wind turbines (Pederson & Persson-Waye 2004) which are becoming an increasing feature on the landscape and coastal seascapes as a result of the global drive for non-carbon energy production.

This movement away from carbon based fuels has spawned a considerable potential benefit for the alleviation of environmental pollution with the growing impetus in developing electric cars that have greatly reduced noise output and which should have considerable benefit for sleeping in city centres and near busy roads. Perversely, this then presents a new hazard, brought about by the considerable reduction in noise, as pedestrians and cyclists will have to be aware of quiet vehicles while negotiating roadways, which would increase the potential for accidents. This has an interesting consequence where soundscape researchers will need to develop a suitable artificial sound generated by the vehicle that warns pedestrians of the presence of vehicle but does not add to the noise burden of residents.

There are other established areas of noise-disturbed sleep research such as those concerned with assessing and improving the negative effect on health, healing and recuperation of noise in hospitals and other health care facilities. A recent report (Solet et al. 2010) developed sleep arousal probability threshold curves for 14 hospital-based sounds, e.g. Intra Venous (IV) pump alarms, utilising the Harvard Medical School sleep laboratories where 12 healthy adult subjects slept. The recorded data provided a sleep stage specific arousal probability curves for stepwise (5dB(A)) decibel levels for 40 – 70 dBA. The most disturbing sounds were IV pump alarms and phone ‘rings’. For each of the common hospital noises, recommendations were provided to improve the acoustic environment and reduce the level of disturbance.

## RECENT REVIEWS AND SPECIAL ISSUES

In 2010 there was a Special Issue of the Noise & Health journal published (12; 47) devoted to noise and sleep which contained some of the papers and deliberations presented at the ICBEN-2008 conference. As a result of this publication two points of view emerged which was reflected in the Letters to the Editor in a later issue of Noise & Health (12.2010) about whether or not physiological responses to noise during sleep have meaningful health consequences that are amenable and valid for the construction of dose-response curves. One realization to emerge from the debate was the difference between the European view of health, which can include mental and physical well-being, not just the absence of disease, while the US position tends to be more pragmatic. Elucidation of the mechanism by which noise-disturbed sleep leads to significant reduction in health is a primary goal to resolve this issue.

There have been a number of reviews of the literature in the last 3 years on the effect of noise on sleep. The BEL Report (2009) set out to estimate dose-response relationships between noise exposure and health impacts in the UK which focused on the ‘key’ outcomes of cardiovascular effects, hypertension and sleep disturbance. However, they found that despite sleep disturbance being a well developed area with robust data, no consensus on any single dose-response relationship between noise level and sleep disturbance could be used to inform a cost-benefit analysis. Also, they concluded that no quantitative link could be established between sleep disturbance due to noise and any long term adverse health effects. But it was possible to find a robust link between noise exposure and hypertension. The authors considered that further research was needed to investigate the links between noise and air pollution and links between transient sleep disturbance and long term health effects.

Another review (Jones 2009) of aircraft noise and sleep disturbance in 2009 was carried out for the CAA (UK) and found results inconclusive and often contradictory with considerable practical design difficulties. The author suggested the need for large-scale long-term epidemiological field studies that include cardiovascular and hormonal measures at various exposure sites. The study should include actigraphy and some polysomnography for calibration and validation, to resolve the links between environmental noise, sleep disturbance and health.

A further review (Partner Project 2010) funded by the Partnership Program in the US and Canada concluded that aircraft noise can cause sleep fragmentation which can involve increases in the number and length of awakenings, reduced SWS and REM and increased heart rate and blood pressure, reduced subjective sleep quality, increased sleepiness and annoyance but only a small effect on performance next day.

## OUTSTANDING ISSUES

There are a number of outstanding issues which need to be considered and addressed in any further research work. It is very difficult to attribute long term health effects directly to sleep disturbance as it takes several years for these illnesses to become apparent (Babisch 2006) and many potential risk factors have been identified in the genesis of cardiovascular disease.

There are various methods employed in sleep recording (van de Water et al. 2011) and each has its own advantages and definition of disturbed sleep so some appropriate combination of methods would seem the most acceptable way forward to reduce the cost and ‘method bias’.

Site and subject selection in any future field study is important as it seems to the current author that a good proportion of residents near to airports or busy roads etc may represent ‘noise survivors’ who did not avoid buying a property near to a major noise producer and individuals who have not moved away because they are able to cope with the noise.

Age and socioeconomic status are major co-factors in considerations of noise and health and its end-points e.g. sleep disturbance, where healthy young adults tend to be generally good sleepers while the middle-aged and elderly tend to have poorer sleep with increased susceptibility to disturbance and fragmentation as a result of noise. Higher socioeconomic status allows individuals to chose homes in more desirable areas which usually involve high levels of 'peace and tranquility' and are able to afford high levels of sound attenuation in city center locations.

It is hard to imagine an individual who suffers routine sleep disturbance who is not also highly annoyed with the noise source, so the strong links between annoyance and sleep disturbance need to be considered in the design and planning.

Someone who lives in a noisy neighborhood and is disturbed at night by noise is likely to have a significant daytime noise load particularly at weekends, so the sleep disturbance may be a result of both exposures and this needs careful consideration.

The potential link between air and noise pollution is frequently mentioned but rarely studied. An exception was Sorensen et al. (2011) who found that exposure to residential road traffic noise was associated with a higher risk of stroke among older people (>64.5 yrs) after controlling for air pollution.

## FURTHER RESEARCH NEEDS FOR ENVIRONMENTAL NOISE AND SLEEP

A very recent submission from the ENNAH project to the EU provides a clear lead and summarizes what new research is needed. 'New research on sleep should address the mechanisms by which noise disturbs sleep, and how noise-disturbed sleep may lead to health effects. This insight is needed to predict the impact of noise events and to evaluate the effectiveness of possible measures to reduce the impact of night-time noise exposure. There needs to be an appreciation of groups vulnerable to sleep disturbance and studies of sleep in those with chronic diseases. Future research may include assessing the effects of combined noises and combined environmental stressors on sleep. This may be carried out in extended field studies with new cost-effective methods of recording disturbance including cardiac arousals, as well as established measurement tools such as actimetry and subjective assessment.

Furthermore, studies are needed to quantify the impact of emerging noise sources such as high speed rail and wind turbine noise and the impact of interventions to reduce noise.

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# Experimental shift work and noise exposure during sleep

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## INTRODUCTION

Though the necessity of night work is debated in some areas of work, night work is concerning the health sector, security and the supply with energy, water etc. essential for the functioning of human societies. This type of work is, however, critical as it takes place when performance capacity is low and sleep is scheduled for a time when performance capacity is high. This work schedule leads to severe sleep disturbances particularly to reduced sleep, followed by sleepiness during work, performance decrements and an elevated risk for accidents (Åkerstedt 2007). To these effects contribute on the one hand the disturbance of the circadian system and on the other hand the fact that noise levels are during the day by 8-15 dBA higher than during nights. As only a very few studies were done on the effects of noise during day sleep, the present study focused on this topic where in addition to the polysomnographic recording and evaluation of sleep after-effects were ascertained, namely sleepiness, subjective sleep quality as well as sleepiness and performance as measured with various performance tests during 8-hour work shifts.

## MATERIAL AND METHODS

*Participants.* Forty-eight healthy and normal hearing students (23 male, 25 female; 19 – 30 yrs) participated and gave their written informed consent to the study which was approved by the local Ethics Committee.

*Experimental design and noise load.* The participants worked in a balanced order four consecutive early shifts (8-16 h) and four consecutive night shifts (23-7 h). Each shift was preceded by 8 hours in bed. Participants slept in separate sound shielded rooms with a background noise of 28 dBA as produced by the air conditioning. No further noise was presented in the first and another randomly chosen sleep period. During the six other sleep periods the background noise was three times each superimposed by railway and by road traffic noise with equivalent levels between 41.9 and 55.9 dBA. The noises were recorded along three railway tracks and in three roads at three and two distances respectively (see Table 1). Recordings were then filtered and attenuated to simulate tilted windows. The order of the noises was randomized but each participant was in one sleep period each exposed to 40 train pass-bys ($L_{Aeq}$ = 49.4 dBA: Rail 4) and to 4,300 car pass-bys ($L_{Aeq}$ = 44.6 dBA: Road 4) respectively.

*Experimental procedure.* After the fixation of the electrodes for the registration of the polysomnogram (PSG) the participants went to bed at 23 h before early shifts and at 14 h before night shifts and were woken up eight hours later. They then estimated their actual sleepiness. Eight hour experimental work shifts started one hour after the wake-up call. During work shifts performance tests were completed hourly for about 25 minutes and sleepiness was rated every hour.

**Table 1:** Equivalent noise levels ($L_{Aeq,8h}$) for the rail and road scenarios at the ear of the sleeper

| Recording distance | **Number of train pass-bys (2200 – 0600 h)** n = 20 | n = 40 | n = 58 |
|---|---|---|---|
| 100 m | 41.9 dB (Rail 1) | 46.3 dB (Rail 3) | |
| 50 m | 44.9 dB (Rail 2) | 49.4 dB (Rail 4) | 50.5 dB (Rail 5) |
| 25 m | | 53.5 dB (Rail 6) | 54.3 dB (Rail 7) |
| | **Number of road vehicles (2200 – 0600 h)** n = 1 300 | n = 4 300 | n = 8 600 |
| 32 m | | 41.2 dB (Road 1) | |
| 26 m | | | 49.1 dB (Road 6) |
| 20 m | 42.3 dB (Road 2) | 44.6 dB (Road 4) | |
| 15 / 14 m | 43.1 dB (Road 3) | (44.6+4)dB (Road 5) | 55.9 dB (Road 7) |

## Data collection and evaluation

The polysomnogram (PSG) was recorded throughout the time in bed. Parameters derived from each PSG where: latencies to sleep onset [SOL] and to the first epoch of slow-wave-sleep [SWSL], the times spent in sleep stages S1, SWS, SREM (for the first sleep cycle and the sleep period time (SPT)), intermittent wakefulness [WASO], total sleep time [TST = SPT - WASO], number of awakenings > 3 minutes. Further, the Sleep Efficiency Index [SEI = TST/SPT] and the Sleep Disturbance Index (SDI [Griefahn et al. 2008]) were calculated, the latter integrating seven sleep parameters thus allowing a reliable and valid estimate of the alterations of sleep structure.

Sleep quality was rated after awakening using analogue scales [Griefahn et al. 2006]. Sleepiness was rated after awakening and hourly during each work shift while using the Karolinska Sleepiness Scale (KSS [Åkerstedt & Gillberg 1990]).

*Performance tests.* The following tests were hourly performed in a random order. Three tests (Go/Nogo, DAT, WMT) were taken from the test battery of attentional performance (TAP [Zimmermann & Fimm 2002]).

- Selective Attention (Go/Nogo). Five differently patterned squares are shown randomly on a screen. A key must be pressed if either of two previously shown squares occurs.
- Divided Attention (DAT). A visual and an auditory task are given simultaneously. On the visual task (DATv), a key must be pressed if four “x”s on the screen form a square. The auditory task (DATa) consists of alternating high and low tones. A key must be pressed if this succession is disrupted.
- Working Memory (WMT). One-digit numbers are presented on a screen and a key must be operated if a digit is the same as the penultimate digit.
- Psychomotor Vigilance (PVT). In this 10-min test a key must be pressed as soon as a millisecond counter starts counting with random intervals of 1 to 10 s.

RESULTS

Awakenings were regarded as noise-induced if they occurred within a minute after the onset of an individual noise. For the clearly intermittent railway noises the probability of awakenings was significantly related to the maximum levels of the individual noises (Figure 1). Significant influences were the rise time, the duration of noise-free intervals, gender, elapsed sleep time and REM-sleep (Table 1). Concerning road traffic noise many pass-bys were due to the high traffic density not clearly distinguishable. Defining single noise events by emergences of at least 10 dBA the detected numbers of events decreased with increasing traffic volume and were differently distributed. The maximum occurred within the first and the second half or in the middle of the night in the scenarios with 1,300, 4,300 and 8,600 pass-bys respectively. The dose-response relation was by far not as clear as for railway noises (Fig. 1) and influenced, additionally as found for railway noises by age, SWS and time of day (night sleep, day sleep). The method of detecting road noise events might be debatable, however.

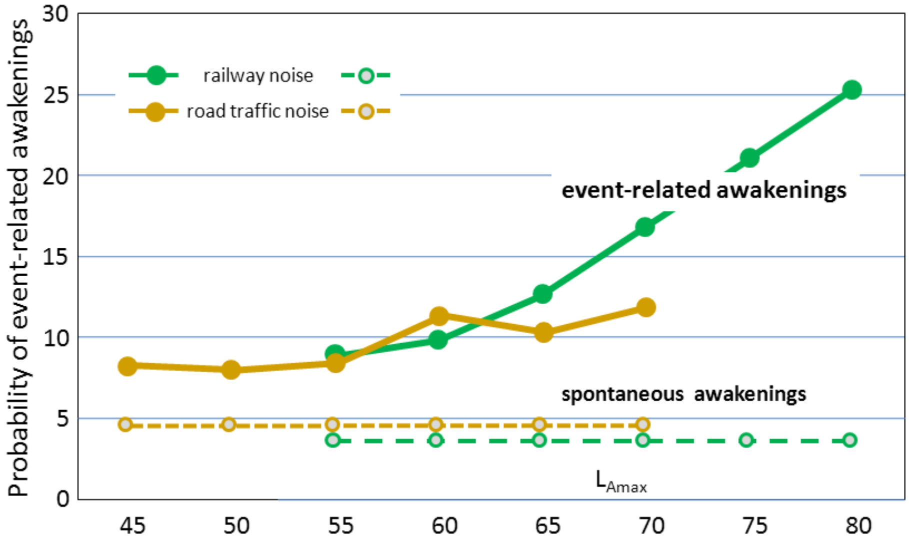


**Figure 1:** Probability of event-related awakenings due to railway noise and to road traffic noise related to the maximum levels of the pass-bys

**Table 1:** Logistic regression analysis of awakening probabilities due to train pass-bys. Influence of physical noise parameters, individual and situational factors. ß: ß-coefficient; SE: standard error; p: p-value; +: p < 0.10; *: p <0.05; **: p <0.01, ***: p <0.001.

| | **4 226 pass-bys** | | |
|---|---|---|---|
| | ß | SE | p |
| ***Physical parameters*** | | | |
| Maximum level | 0.055 | 0.011 | *** |
| Rise time | 0.067 | 0.036 | **+** |
| Noise duration | 0.001 | 0.002 | |
| Noise-free interval | 0.001 | 0.000 | *** |
| ***Individual parameters*** | | | |
| Age | -0.052 | 0.033 | |
| Noise sensitivity | -0.001 | 0.010 | |
| Gender | 0.338 | 0.175 | + |
| ***Situational parameters*** | | | |
| Elapsed sleep time | 0.000 | 0.000 | *** |
| SWS | 0.009 | 0.123 | |
| REM-sleep | -0.723 | 0.116 | *** |
| Shift type | 0.005 | 0.093 | |

Table 2 shows means and standard deviations of the physiological parameters of the sleep structure and of subjective evaluation for sleep periods in respectively after quiet and noisy conditions and separately for night and day sleep. (As there was no difference between rail and road traffic, these noises were combined.)

**Table 2:** Alteration of sleep structure during nights and days due to noise. ANOVA-comparison between noise-free and noisy sleep periods. means (AM), standard deviation (SD) and p-values ($p \le 0.1$: +, $p \le 0.05$: *, $p \le 0.01$: **, $p \le 0.001$: ***)

| | **Night sleep** | | | | | **Day sleep** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Quiet** | | **Noise** | | | **Quiet** | | **Noise** | | |
| Dependent variables | n = 20 AM | ± SD | n =122 AM | ± SD | Sig-nif Q : N | n = 20 AM | ± SD | n =123 AM | ± SD | Sig-nif Q : N |
| Sleep onset & 1st cycle | | | | | | | | | | |
| Sleep onset (SOL) | 13.4 | ±12.4 | 15.9 | ±13.3 | | 5.1 | ±4.4 | 8.9 | ±8.8 | * |
| Latency to SWS (SWSL) | 17.7 | ±13.9 | 18.5 | ±11.2 | | 12.9 | ±5.0 | 16.8 | ±13.6 | + |
| SWS (stages 3&4) | 33.2 | ±14.2 | 30.2 | ±16.8 | | 36.1 | ±17.0 | 29.3 | ±16.1 | * |
| REM-Sleep | 21.2 | ±15.8 | 18.6 | ±10.9 | | 17.0 | ±10.2 | 19.3 | ±10.7 | |
| Total sleep period | | | | | | | | | | |
| Sleep period time (SPT) | 461.5 | ±15.8 | 459.9 | ±17.4 | | 440.4 | ±60.7 | 452.1 | ±46.7 | |
| Total sleep time (TST) | 441.1 | ±16.5 | 434.5 | ±25.9 | | 406.5 | ±61.3 | 414.4 | ±51.6 | |
| Wakefulness (WASO) | 20.5 | ±12.7 | 25.4 | ±16.5 | | 33.8 | ±35.3 | 37.7 | ±34.3 | |
| Number periods awa-ke | 20.6 | ±7.6 | 21.3 | ±7.7 | | 16.7 | ±7.5 | 18.3 | ±7.7 | |
| SWS (stages 3&4) | 70.9 | ±21.9 | 61.4 | ±28.8 | | 73.8 | ±25.9 | 70.5 | ±29.1 | |
| REM-sleep | 124.2 | ±29.9 | 117.9 | ±22.6 | | 96.3 | ±32.1 | 98.2 | ±24.5 | |
| Sleep efficiency-Index | 0.96 | ±0.03 | 0.94 | ±0.04 | + | 0.92 | ±0.07 | 0.92 | ±0.07 | |
| Sleep disturbance-Index | -0.66 | ±0.85 | -0.11 | ±0.97 | ** | -0.54 | ±1.26 | -0.06 | ±1.21 | |

Apart from SPT, TST and the time in REM-sleep during day sleep all the other physiological parameters revealed alterations due to noise in the expected direction but with different extents for night and day sleep. During day sleep noise was associated with significantly longer latencies to sleep onset and to SWS and a significantly shorter SWS-time in the first sleep cycle. In contrast noise related decreases of the SEI and the SDI were significant only during night sleep.

Similar as for the physiological variables the assessments of sleep under quiet and noisy conditions were for night and day sleep in the same direction. Subjective sleep quality was rated significantly less and sleepiness was higher after sleep in noisy than in quiet conditions.

During the 8-h work shifts the participants completed several performance tests and rated their actual sleepiness every hour. Figure 2 shows the course of sleepiness beginning with the ratings immediately after awakening. Sleepiness decreased considerably during the first hour post-awakening but was throughout the work shift clearly higher after sleep in noise than after sleep in quiet. Though measured with a questionnaire this result is supported by physiological measurements (Basner et al. 2008), i.e. a higher value of the pupillary unrest index after sleep in noise.

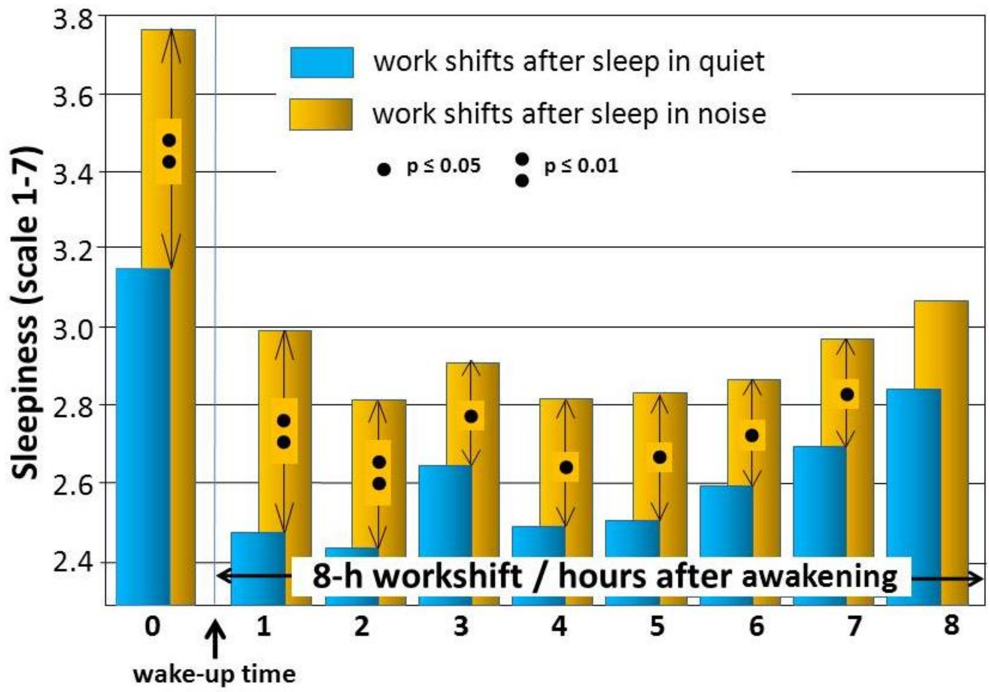


**Figure 2:** Sleepiness ascertained immediately after awakening and then hourly during work shifts.

Performance decrements after sleep in noise concerned predominantly the quantitative rather than the qualitative aspects of performance (Figure 3). Reaction times were prolonged in the PVT and in the WMT. The acoustic part of the DAT, however, revealed shorter reaction times after sleep in noise than after sleep in quiet over the entire work shift.

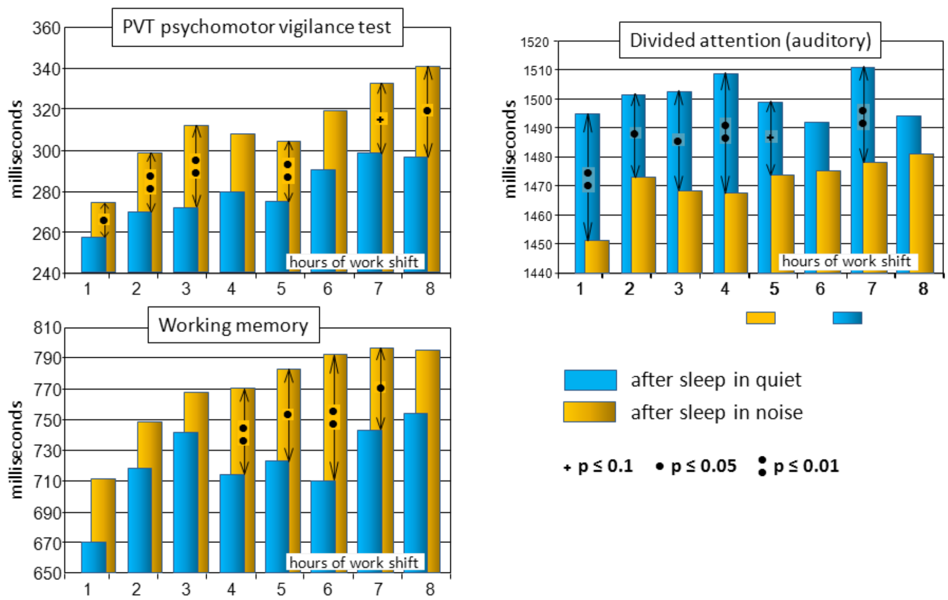


**Figure 3:** Reaction times ascertained hourly during work shifts after sleep in noise and in quiet

Concerning the after-effects of noise-induced sleep disturbances ascertained in terms of sleepiness and performance during the following work shifts there were again no significant differences between day shifts and night shifts though the reaction times were moderately longer after day sleep in noise than after night sleep in noise.

## DISCUSSION

Though approximately 20 % of the workforce is currently involved in shiftwork the interaction between shiftwork and noise exposure during sleep has scarcely been studied. A very few investigations on the effects of noise on day sleep performed in the 70s and in the 90s with a rather limited number of participants [Knauth & Rutenfranz 1972, Nicolas et al. 1993] suggested that noise causes stronger effects on day sleep than on night sleep. This motivated the present study where 48 persons worked 4 consecutive 8-h work shifts each, during the day and during the night in a balanced order. Each shift was preceded by an 8-h period in bed during which the participants slept in quiet or were exposed to traffic noise with equivalent noise levels between 41.9 and 55.9 dBA. This is the first study that concerned not only physiological measurements and the subjective evaluation of sleep but also sleepiness and performance during the following 8-h work shift.

Night workers suffer first of all from sleep disturbances. They sleep usually 2-4 hours less after night than after day shifts. These disturbances are mainly caused by the disruption of the circadian rhythm but certainly enhanced by unfavorable environmental conditions such as elevated levels of light, temperature and noise.

In this study the sleep period time and total sleep time were not more than 20 and 35 minutes respectively shorter and intermittent wakefulness was not more than 13 minutes longer during day than during night sleep. The discrepancy concerning the extended sleep loss after real night work and the rather moderate reduction of day sleep after the night work in the present study is a rather common finding in experimental studies on shift work and certainly related to the fact the participants had no further obligations. This was, however, advantageous insofar as this study tested the hypothesis that day sleep is per se more interruptible than night sleep. The participants in this study were therefore exposed to the same noise load during day and during night sleep. This hypothesis was, however, not verified. Instead, the same noise caused similar effects during day and during night sleep. This was not only true for the moderate alterations of the sleep structure but also for event-related awakenings caused by railway noises. Road traffic noises revealed, however, differences between day and night but there are serious doubts concerning the detection of the events as done here by emergences of 10 dB.

In consequence to the equal disturbances of day sleep and of night sleep by the same noises there were no differences in the after-effects on sleepiness and performance during the following work shifts.

Despite the lacking differentiation between noise exposure during sleep at night and at day this study revealed the first time a clear effect of noise during sleep on sleepiness and performance during the entire following work shifts. Noise exposure during the time in bed was, as compared to sleep in quiet, followed by a significantly higher sleepiness. Similar results were up to now reported for much shorter observation periods, namely the first hour post-awakening from night sleep (Basner et al. 2008; Griefahn et al. 2006). This after-effect is regarded as critical as sleepiness is often associated with reduced performance and elevated risks of accidents.

The performance decrements found here concerned primarily the executive functions that have previously been shown to be impaired by noise-induced sleep disturbances (Elmenhorst et al. 2010; LeVere et al. 1972, 1975; Öhrström 2000) and due to disturbances of the circadian system (e.g. Wilkinson & Houghton 1982). They concerned the quantitative rather than the qualitative aspects. The reaction times were after sleep in noise significantly longer and these decrements were similar as the increase of sleepiness – more or less equally spread over the entire work shift. The courses of these alterations differ significantly from those observed after chronodisruption. Performance decrements concern then rather the qualitative than the quantitative aspects of performance i.e. the error rates that increase gradually and considerably during night shifts but scarcely during day shifts.

The auditory part of the DAT, where the interruption of the sequence of 2 tones has to be detected, revealed, however, shorter reaction times after sleep in noise. This surprises at the first glance but it is well-known that the brain is even during sleep able to perceive external stimuli, to analyze them and to react adequately (Bastuji et al. 2002). Thus, it might be speculated that noise during sleep might cause a sensitization to auditory stimuli and lead to an increased readiness to react to acoustic stimuli during the consecutive time awake.

## CONCLUSIONS

Overall, noise exposure during sleep caused alterations of sleep structure, increased sleepiness and impaired performance during the consecutive work shift that were not influenced by the temporal location of sleep (night, day). In the real life situation noise effects are expected to be much stronger as shift workers sleep much less after night than after day shifts and under the impact of noise with a much higher equivalent noise level (8-15 dBA). Moreover, day time noise scenarios contain a lot of particularly disturbing noises such as phone ringing, door bells, children's noise, other neighborhood noises etc. that have been shown by Strauch et al. (1976) and by Oswald et al. (1960) to disturb much more than rather neutral noises. Thus, in this realistic situation shift workers are expected to have stronger sleep disturbances during day than during night sleep. This requires the repetition of this study with a more realistic scenario as well as extended field studies.

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# Acoustic, individual, and situational determinants of vegetative and cortical arousals induced by traffic noise during sleep

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## INTRODUCTION

A recent publication by the World Health Organization (WHO) on the burden of disease from environmental noise concludes that an estimated 1.6 Million healthy life years are lost in the European Union annually (Fritschi et al. 2011). Notably, 903,000 healthy life years lost (or 55.8 %) were attributed to noise induced sleep disturbance, thus acknowledging the importance of undisturbed sleep of sufficient length for health and well-being.

Sleep recuperation is a very active process, and noise-induced disturbance of this process impairs restoration (Muzet 2007; Basner et al. 2010). At the same time, we are not aware of ourselves and our surroundings during sleep (i.e., unconscious). We have thus limited insight into our own sleep process, and self-reports may both underestimate (e.g., in insomnia) or overestimate (e.g., in obstructive sleep apnea) sleep duration and quality. Therefore, physiologic measurements (e.g., polysomnography or actigraphy) have been used to gather objective information on the effects of noise on sleep (Muzet 2007; Basner et al. 2010; Griefahn & Basner 2011). Due to the high methodological expense of physiologic measurements, the field has mostly seen small studies in healthy, young populations with limited representativeness for the exposed population (Basner et al. 2010). These studies consistently show that whether or not sleep is disturbed by environmental noise depends on individual, situational, and acoustical factors (see Figure 1) (Marks et al. 2008; Basner et al. 2011). However, this is not reflected in noise policy and regulation, where average noise levels (like $L_{night}$), integrating noise exposure during a specific period (e.g., 23:00 to 7:00) over several months, are often used as the sole criterion. Thus, important acoustical, individual, and situational variables that could be used to better predict and mitigate the effects of environmental noise on sleep are often not taken into account.

Basner argues that a variable should only be included in a prediction model on the effects of noise on sleep if (a) the variable has a relevant impact on sleep, (b) information on the distribution of the variable in the target population is available, and (c) the distribution of the variable in the target population differs relevantly from the distribution in the population that was used to generate the prediction model (Basner 2009). Furthermore, even variables that do not fulfill all of the above criteria may often be used to inform political decision making processes.

Here, we report on the results of a polysomnographic laboratory study on the effects of air, road, and rail traffic noise on awakenings, EEG arousals, and cardiac arousals where several acoustical, individual, and situational variables were taken into account (Basner et al. 2011).

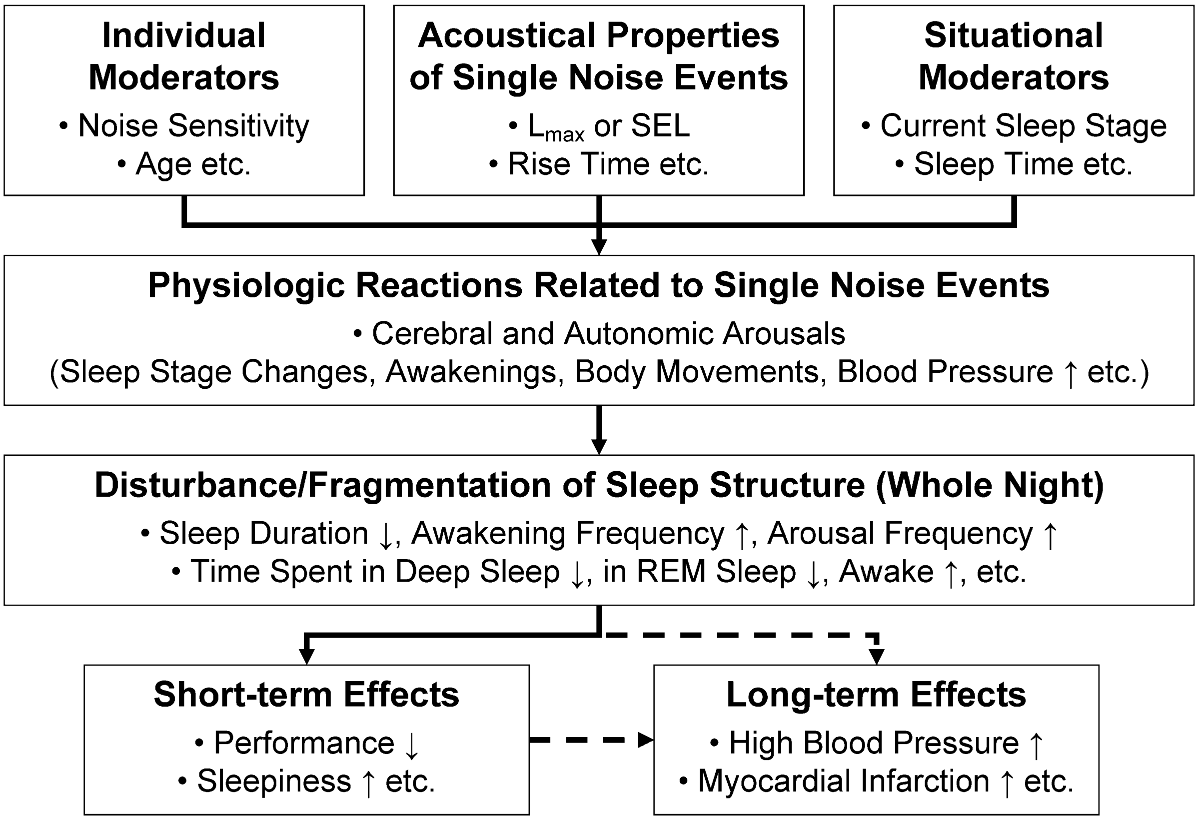


**Figure 1:** Flow chart on the effects of traffic noise on sleep. $L_{max}$ = maximum sound pressure level, SEL = single event level.

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METHODS

We polysomnographically investigated 72 healthy subjects (40 ± 13 years, range 18-71 years, 32 male) for 11 consecutive nights each in the sleep laboratory of the German Aerospace Center (DLR) in Cologne. Physiological variables included the electroencephalogram (EEG: C3-A2, C4-A1), the electrooculogram (EOG), the electromyogram (EMG), the electrocardiogram (ECG), respiratory movements of rib cage and abdomen, and finger pulse amplitude. Additionally, subjects wore actigraphs 24 hours each day. The study included 8 nights with 8 hours time in bed and with exposure to 40, 80, or 120 pre-recorded air, road, and/or rail traffic noise events with $L_{AS,max}$ of 45, 50, 55, 60, or 65 dB, and one noise-free control night. The first night served as adaptation, was noise-free and excluded from the analyses (for a detailed description of the protocol see Basner et al. 2011). The study was approved by the local ethics committee. Subjects gave written informed consent prior to study participation and were free to discontinue the study any time.

This report concentrates on an event-related analysis on the effects of acoustical, individual, and situational variables on EEG awakenings, shorter cortical activations in form of EEG arousals (Bonnet et al. 1992), and changes in heart rate (representing vegetative arousals). Awakenings were defined according to Rechtschaffen & Kales. (1968) as sleep stage changes from any sleep stage other than wake to stage wake.

By design, noise events started exactly at the beginning of a sleep epoch, which was then defined as the first epoch under the influence of noise. A noise event was excluded from the analysis if the subject was already awake in the epoch preceding the first noise epoch. Therefore, noise events outside of the sleep period time, i.e. before sleep onset or after final awakening, were also excluded from the analysis. The first noise epoch and the epoch following it were screened for an EEG awakening, as this maximized the difference in awakening probability with and without noise exposure (i.e. signal to noise ratio).

For EEG arousals, a 60 s window following the beginning of a noise event was screened for arousal onset. This way, noise events from the three traffic modes were compared on an equal footage, and comparisons with the analysis based on EEG awakenings were facilitated. The noise event was only included if it fell within sleep period time (SPT) and if the 10-s interval preceding noise onset was free of EEG arousals.

For heart rate analysis, heart beats with inter-beat intervals (IBI) > 2 s or < 500 ms (corresponding to heart rates of < 30 bpm and > 120 bpm) were considered invalid (less than 0.2 % of all beats). Nights where valid heart beats covered less than 95 % of SPT were excluded from the analysis (N=28). For each noise event, maximum heart rate was identified in a 60 s time window following noise onset. Then, average heart rate was calculated for an interval ±10 s relative to the moment when maximum heart rate occurred. The same procedure was repeated for a 30 s time window preceding noise onset. The difference between average heart rate after and before noise onset was calculated and constituted the outcome variable for the event-related analysis. This difference increases both with amplitude and duration of a noise-induced heart rate response. Noise events were excluded from analysis if the screening window contained > 10 % invalid heart beats (see above) or a single heart beat with an IBI > 6 s.

Altogether, 31,266 noise events contributed to the analysis of awakening probability, 29,151 noise events contributed to the analysis of arousal probability, and 30,224 noise events contributed to the event-related heart rate analysis. Proc NLMIXED (SAS 9.2) was used to perform random subject effect regressions. For the awakening and arousal data, random subject effect logistic regression was performed. The dichotomous dependent variable was classified as 1 for an awakening or arousal and 0 for no awakening or no arousal. For the heart rate data, random subject effect linear regression was performed.

Several independent variables were considered as predictors or mediators: two indicator variables for traffic mode, contrasting air and rail traffic with road traffic (reference), maximum sound pressure level, age, gender, sleep stage in the epoch preceding the noise event with stage 2 as reference, elapsed sleep time since sleep onset, study night (2-11), the number of noise events per night with single exposure nights (40 noise events) serving as reference, noise-free interval between the end of the last and the beginning of the current noise event, noise event duration, sound pressure level rise time, and octave band energy for mid frequencies from 31.5 Hz to 8 kHz. Here, we report on the effects of individual, situational, and acoustical variables for the fully adjusted model. All continuous variables were mean-centered and inspected for linearity in the logit of awakening and arousal probability, and in heart rate changes, respectively. Based on the results of this analysis, maximum sound pressure level (SPL) was the only variable to enter the models non-linearly.

## RESULTS AND DISCUSSION

Table 1 summarizes the findings of the multivariable random subject effect regression models. Variables that promote EEG awakenings, EEG arousals, or cardiac arousals are shaded red, those that are associated with a decrease in EEG awakening or EEG arousal probability or heart rate are shaded green. The level of statistical significance is indicated by stars (★p<0.05, ★★p<0.01, ★★★p<0.001, ★★★★p<0.0001, statistically non-significant effects have a white background).

**Table 1**: Findings of the event-related analyses

| | **EEG Awakenings** | **EEG Arousals** | **Cardiac Arousals** |
|---|---|---|---|
| ***Acoustical moderators*** | | | |
| $L_{AS,max}$ [dB] | ★★★★ | ★★★★ | ★★★★ |
| SPL rise time [dB/s] | ★★ | ★★★ | ★ |
| Octave energy 31.5 Hz [dB] | ★★★ | | |
| Octave energy 63 Hz [dB] | | | ★ |
| Octave energy 125 Hz [dB] | | | ★★ |
| Octave energy 500 Hz [dB] | ★ | | ★ |
| Octave energy 4 kHz [dB] | ★★★★ | ★★★★ | ★ |
| Octave energy 8 kHz [dB] | ★★★★ | ★★★★ | ★★★★ |
| ***Individual moderators*** | | | |
| Age [years] | | ★ | ★ |
| Male gender | ★ | ★ | ★★ |
| ***Situational moderators*** | | | |
| Sleep stage S1 vs. S2 | ★★★★ | ★★★★ | ★★★★ |
| Sleep stage SWS vs. S2 | ★★★★ | ★★★★ | ★★★★ |
| Sleep stage REM vs. S2 | ★★★★ | ★★★★ | ★★★★ |
| Elapsed sleep time [h] | ★★★ | | ★★★★ |
| Study night [d] | ★★ | ★ | |
| 80 vs. 40 noise events | ★★★ | ★★★★ | ★★★★ |
| 120 vs. 40 noise events | ★★★★ | ★★★★ | ★★★★ |

SPL = sound pressure level; $L_{AS,max}$ = maximum SPL; SWS = slow wave sleep; REM = rapid eye movement sleep; mid frequencies are given for octave bands; adopted from Basner et al. (2011)

### Acoustical moderators

**Rise time**: Beside the maximum sound pressure level $L_{AS,max}$, central nervous system arousal probability increased with sound pressure level rise time. Nocturnal speed limits both decrease sound pressure levels and sound pressure level rise times, and could therefore effectively be used to decrease noise induced sleep disturbance.

**Spectral composition**: Sound energy especially in the high frequency domains > 3 kHz were associated with higher arousal probabilities. The spectral composition of the noise events was able to explain the differences between the effects of air, road, and rail traffic noise on cortical and cardiac arousal probability that were seen in descriptive statistics and unadjusted models. Because of atmospheric absorption of high frequency components of aircraft noise but not of road and rail traffic noise, aircraft noise was associated with significantly lower arousal probabilities relative to road and rail traffic noise (Marks et al. 2008; Basner et al. 2011). These findings may have implications for the design of active and passive noise control measures, and for the optimization of the sound design of the noise source. The variables “noise event duration” and octave bands with mid frequencies of 250 Hz, 1 kHz, and 2 kHz were statistically non-significant (P>0.05) and thus removed from the final models.

### Individual moderators

**Age**: Our models indicate a non-significant increase in awakening probability, a significant increase in EEG arousal probability, and a significant decrease in heart rate response with increasing age. A similar study by Marks et al. (2008) found significant increases in awakening probability only after the data of air, road, and rail traffic noise were combined into a single model. However, one has to keep in mind that the effect of age was adjusted for several other situational and individual moderators. Thus, the age variable will only show effects in excess of what is already explained by the other variables (e.g., sleep stage distribution varies with age, and the momentary sleep stage is a potent predictor of arousal probability, see below). In this light, our findings corroborate that older age is an important risk factor for noise induced sleep disturbance.

**Gender**: Arousal probabilities were consistently higher for male relative to female study participants. Marks et al. (2008) saw no statistically reliable gender effect on awakening probability, and an earlier study on the effects of aircraft noise on sleep found slightly higher awakening probabilities for female subjects (Basner et al. 2004). These discrepancies may be explained by the relatively low sample sizes. Larger studies are needed to clarify whether one sex is more at risk for noise induced sleep disturbance than the other. Some epidemiological studies suggest that there are differences in the effects of noise-induced cardiovascular disease between men and women (Babisch et al. 2005).

**Noise sensitivity**: Although we did not test for the significance of subjectively perceived noise sensitivity as an individual moderator, both Marks et al. (2008) and Basner et al. (2004) found no statistically reliable effect of noise sensitivity on awakening probability.

### Situational moderators

**Sleep stage**: The momentary sleep stage is a potent moderator for the effects of noise on arousal probability. Arousal thresholds were highest for slow wave sleep (SWS, also called "deep sleep"), followed by REM sleep, S2 sleep, and S1 sleep. As SWS is predominantly seen during the first half of the night, this part of the sleep period is often considered less vulnerable for the effects of noise on sleep (although it is unclear whether or not the disturbance of SWS is associated with a higher "physiological cost" compared to, e.g., the disturbance of S2 sleep). As SWS amounts decrease with age, older subjects are usually more easily aroused from sleep, while it is harder to arouse children. The latter are nevertheless regarded a group at risk, as they are in a vulnerable developmental life period. At the same time, subjects with a genetically determined shallow sleep or insomnia (who have trouble initiating and maintaining sleep) may be at greater risk for noise induced sleep disturbance.

**Elapsed sleep time**: Additional to these sleep stage effects, awakening probability and heart rate increased with elapsed sleep time (EEG arousal probability increased statistically non-significantly), again pointing to a higher vulnerability of sleep towards the end of the night. Due to the decreased sleep pressure in the early morning, subjects are not only more easily aroused from sleep, but it is also harder to re-initiate sleep after a spontaneous or noise-induced awakenings (Basner & Siebert 2010).

**Repeated exposure**: We also observed significant habituation effects for EEG awakenings, EEG arousals, and cardiac arousals within a single night (i.e., arousal probabilities per noise event were lower in nights with a higher number of noise events). This effect was also seen for EEG awakenings and EEG arousals across study nights (i.e., arousal probability decreased from study night 2 to study night 9). These habituation effects are most likely caused by a decrease in the importance of noise events due to repeated stimulation, and it seems biologically plausible in terms of sleep homeostasis and energy conservation. It is unclear whether this effect represents true habituation or whether it can be, at least in part, explained by increased arousal thresholds due to noise-induced sleep fragmentation in previous exposure nights or in preceding parts of the same night. According to Bonnet (1985), both is probably true. Interestingly, cardiac arousals did not habituate across nights, corroborating earlier findings (Griefahn et al. 2008) and stressing the potential relevance of nocturnal cardiac arousals for the genesis of long-term cardiovascular health effects. The variable “noise-free interval” was statistically non-significant (P>0.05) and thus removed from the final models.

## CONCLUSIONS

These results stress that the degree of noise-induced sleep disturbance depends on several acoustical, situational, and individual variables. This knowledge can be used to improve predictions of aircraft noise effects on sleep and improve mitigation measures. Relying on average noise levels alone for regulation purposes fails to properly address the complex interactions between acoustical, situational, and individual factors. Noise prediction models need to be further improved in order to reliably predict the time course and spectral composition of single noise events. Field studies on more representative populations are needed for validation of our results in a setting with higher ecologic validity.

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# A comparison of noise-induced sleep disturbance predictions around airports using awakening models and simplified sleep structure based models

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## ABSTRACT

Nighttime aircraft noise has been found to increase the number of awakenings as well as affect time spent in different stages of sleep. There are existing models that could be used to predict changes in sleep structure due to noise. However, there is a question of whether the added complexity of these models would result in significantly improved predictions of the number of people impacted by nighttime noise over that predicted by simpler models that exist. In order to examine this question, existing sleep structure models had to be modified to incorporate a noise level dependence, as most only predict normal sleep patterns. Different methods for introducing this dependence were examined in order to reproduce results found in various airport noise studies. In order to make comparisons between community impact predictions from these and existing sleep disturbance models, flight operations data from several US airports were obtained and noise exposure was predicted. To assess sleep impact the number of awakenings and various sleep quality indices were calculated using one or more of: $L_{night}$, dose-response awakening models, the ANSI/ASA S12.9-2008 Part 6 standard, and the modified sleep structure models. Differences and similarities in the predictions of sleep disturbance for a number of different sets of flight operations are discussed.

## INTRODUCTION

In order to predict the effect of nocturnal transportation noise on communities several models have been developed. These models range in complexity from the simplest which are cumulative metrics such as $L_{night}$ to the most complex which is to predict the effect of noise on time spent in different stages of sleep. To develop models and also to decide which to use to predict community impact, predictions from different models need to be compared for a variety of flight operations scenarios. Differences and similarities in predictions need to be evaluated. Also it needs to be examined whether increasing model complexity leads to improved predictions of community impact compared to predictions from simpler models.

Understanding the similarities and differences between model predictions is also important when considering the type of data that should be collected as part of future studies in order to validate proposed models. If survey data is only collected for flight operations in which all models produce very similar results then it will not be possible to highlight the pros and cons of the various modeling approaches. Using flight operations data from different types of airports along with census and community data, sampling strategies for future surveys can be studied and refined so that the right type of data can be collected to enable a comprehensive evaluation of the different models. Of particular interest is gathering data that enables models to be updated and their parameters estimated better, i.e. with less uncertainty (variance).

To examine sleep disturbance model predictions, data was obtained from US airports. Different flight scenarios were created and single and cumulative noise metrics were calculated. Comparisons between noise metric values, predicted number of awakenings and changes in sleep structure for the different scenarios using several existing models were made.

## SLEEP MODELS

The use of $L_{night,outside}$ was examined. In the World Health Organization's Night Noise Guidelines for Europe (WHO 2009) it was recommended that outside noise levels be below 40 dB at night to prevent adverse health effects. As such a limit would be difficult to obtain a target goal of 55 dB was proposed. One limitation though of using $L_{night}$ as a predictor of sleep disturbance is that the same $L_{night}$ could be obtained from different combinations of numbers and levels of aircraft events. Therefore, Basner et al. (2009) have suggested using number of events to supplement $L_{night}$.

Several awakening models were also examined. The most common type of awakening models are dose-response relationships which relate the indoor noise level of the event measured with either $L_{Amax}$ or *SELA* to the percent awakened (e.g. Basner et al. 2006; FICAN 1997). There is variation between models in the predicted percent awake for a given noise level. One of the primary reasons for this variation is differences in how sleep disturbance was quantified. For example, the FICAN model is based on behavioral awakenings (only captures longer duration awakenings) but is an upper limit of the data it is based on, while the model developed by Basner et al. (2006) is based on awakenings measured by using polysomnography which is a more sensitive measure of awakenings. Also a standard, ANSI/ASA S12.9-2008, has been developed for quantifying noise-induced sleep disturbance. It is based on behavioral awakening dose-response curves and it predicts the percent of the population awakened at least once during the night. In the ANSI standard two models are given; a model in which the probability of awakening is only dependent on noise level and a model that has both noise level and time dependence.

While aircraft noise increases the number of awakenings, it can also change individuals' sleep structure, including reducing the time spent in Rapid Eye Movement (REM) and Slow Wave Sleep (SWS) (Griefahn et al. 2008). There are a few models that could be used to predict these changes. A Markov model based on an autoregressive multinomial logistic regression has been developed by Basner (2006) using data from a DLR laboratory study. It predicts the probability of moving from one stage to another. The output of the model can be used to construct a hypnogram showing the sleep stages an individual is in during the night. Also, there is the potential to use nonlinear dynamic sleep models for predicting changes in sleep structure. This type of model has been used to predict normal sleep patterns and could potentially be adapted to predict noise-induced sleep changes (e.g. Massaquoi & McCarley 1992). The output from both the Markov and nonlinear dynamic models could be used in conjunction with sleep quality indices, which are functions of parameters including the number of awakenings, duration spent in different stages of sleep, and sleep onset latency (e.g. Basner 2006; Griefahn et al. 2008), to predict the total effect of noise on sleep.

## APPROACH

In order to examine sleep disturbance model predictions for different scenarios, flight operations data were obtained for two US airports. The obtained data included flight paths, number of arrivals and departures, types of aircraft, and timing of events. For each airport a list of aircraft present in approximately 90 % of the operations was generated. Noise simulations for this consolidated list of aircraft on multiple flight paths, were completed using the Federal Aviation Administrations Integrated Noise Model (INM) version 7.0b. The data obtained from these simulations consisted of $L_{Amax}$ and *SELA* levels for single aircraft events for a grid spacing of 0.1 nautical miles (nmi). Different operations scenarios were generated and the single event noise levels were used to calculate sleep disturbance using the different models described above. The scenarios are not exact representations of the operations typically found at the airports from which data was obtained. The airports are referred to as Airport A and Airport B throughout this report.

## MODEL PREDICTIONS

A baseline operations scenario was created for each airport. For Airport A the baseline scenario is 150 operations and for Airport B it is 281 operations. The aircraft, runways and flight paths used were assigned randomly based on the percent use calculated from the original files. The percent awakened at least once was calculated using the method as described in the ANSI standard, however different dose-response awakening models were used including the one in the ANSI standard and the FICAN and Basner et al. (2006) model. As the sleep/awakening model predictions are based on indoor noise levels, an outdoor to indoor noise attenuation of 25 dB was used. This level of attenuation is similar to those found or used in various studies (WHO 2009). The results shown in Figure 1 (a,b,c) are for the baseline scenario for Airport A in which the operations are on two parallel runways, while in Figure 1 (d,e,f) 25 of the 150 operations were assigned to a third runway which crossed the other two. A smaller percentage of the population is predicted as being awakened at least once when using the ANSI standard, particularly along the cross runway than when using the FICAN or Basner et al. model.

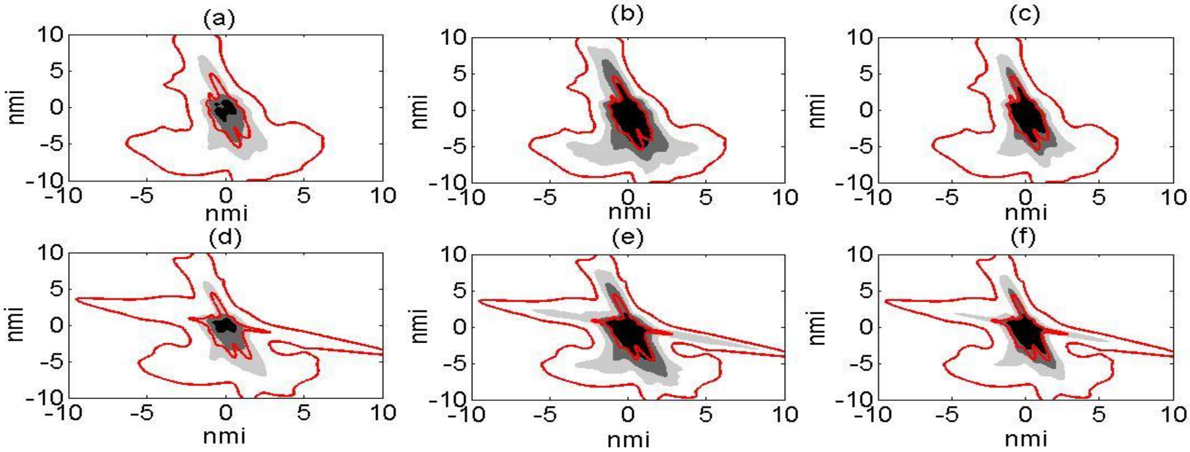


**Figure 1:** Gray-scale shading indicates percent awakened at least once.
Black to dark gray 75 %, dark gray to light gray 50 %, and light gray to white 25 %.
(a,b,c) Scenario 1 and (d,e,f) Scenario 2. (a,d) ANSI, (b,e) FICAN and (c,f) Basner et al. model. Red contours are the 40 and 55 dB $L_{night,outside}$ contours.

In order to examine the number of awakenings that would occur in the community, population data from the 2000 US census was obtained for the two airports that were examined. The total population in each 0.01 $nmi^2$ block for the region of interest was calculated and then multiplied by the percent awakened at least once which was predicted using Basner et al.'s dose-response model. The results are shown in Figure 2. The $L_{night,outside}$ contours are plotted for comparison. At Airport A there are few people residing within the 55 dB contour. For both Airport A and B, those living out to the 40 and 45 dB $L_{night}$ contour are still experiencing sleep disturbance Therefore, using the 55 dB $L_{night}$ contour alone would result in numerous communities erroneously being classified as unaffected by nocturnal noise.

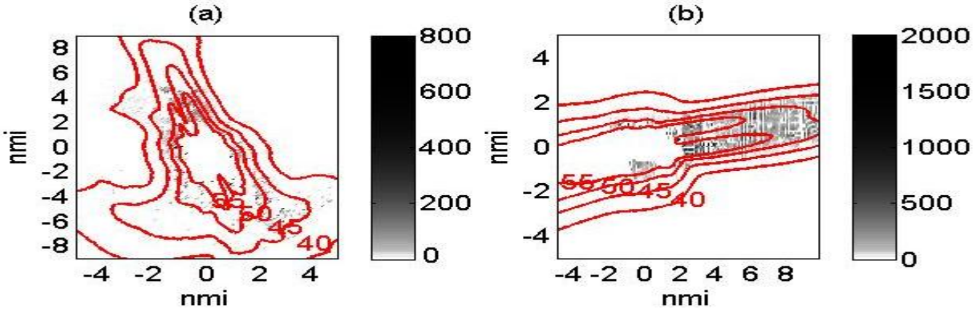


**Figure 2:** $L_{night,outside}$ contours (red) and number of people awakened at least once (gray to black) predicted using Basner et al.'s dose-response relationship for (a) Airport A and (b) Airport B.

Both the ANSI standard and Basner's Markov model contains a time dependence. In order to examine similarities and differences in model predictions for different distributions of aircraft events during the night six different time scenarios were examined. The six scenarios are shown in Figure 3. Scenarios 1 and 4 are similar to nighttime operations at the airports for which data was obtained. The other scenarios were chosen to emphasize the difference between models. A defined number of aircraft events were assigned to each of the 8 hours of the night and within that hour the events were randomly assigned. For simplicity when performing these simulations it was assumed all individuals went to sleep at the same time and that the duration of sleep was 8 hours.

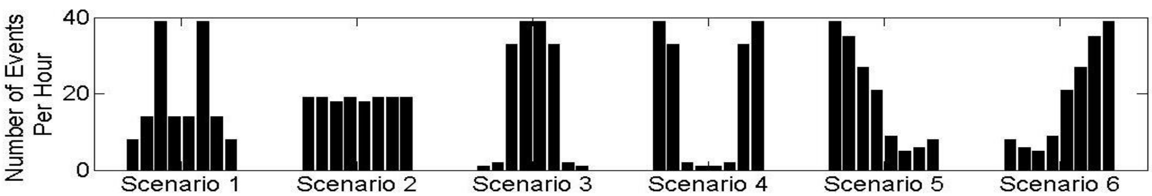


**Figure 3:** Six nighttime scenarios that were examined. Each bar represents the number of events during an hour of the night. There are eight bars per scenario representing each hour from 11 pm to 7 am.

In the ANSI standard, the probability of awakening increases throughout the night. It is lowest at the beginning and highest at the end of the night. Therefore, Scenarios 1, 2 and 3 in which the events were either evenly distributed throughout the night or most of the events were in the middle of the night, produced similar numbers of awakenings. The largest difference in the predicted number of awakenings was between Scenario 5 in which most of the events were at the beginning of the night and Scenario 6 in which most of the events were at the end of the night. A comparison of the average number of awakenings for each of the six scenarios is shown in Figure 4.

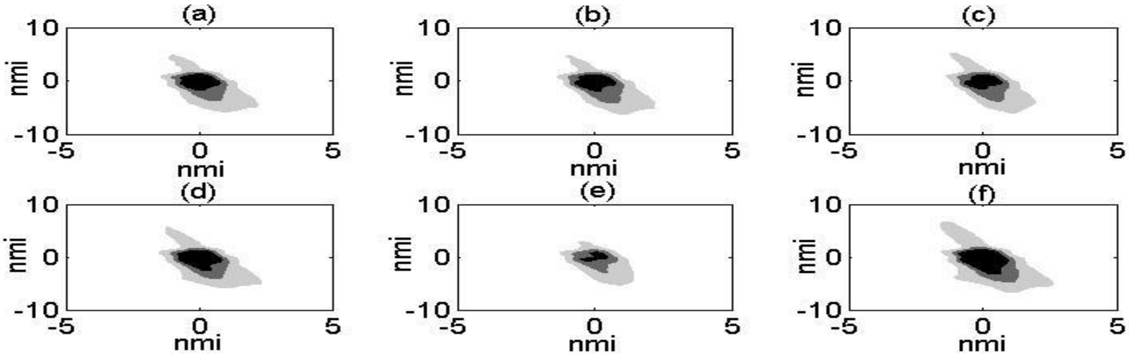


**Figure 4:** Model predictions for Scenario 1 through 6, labeled (a) thru (f) respectively using the ANSI dose-response model. Gray-scale shading indicates the average number of awakenings. Black to dark gray 1.5, dark gray to light gray 1.0 and light gray to white 0.5 awakenings.

In order to examine model predictions with Basner's Markov model for the different time scenarios, first a noise level dependence had to be added to the model. The model only accounts for whether a noise event occurs but not for changes in sleep structure for events of different noise levels. A noise level dependence was added in a similar fashion as previously examined (McGuire & Davies 2008) in that the values of the noise model coefficients were varied with noise level. However, this time they were varied quadratically in order to obtain an increase in awakenings with noise level which matched Basner et al.'s (2006) dose-response relationship. The coefficients that define the time dependency in the model were not varied with noise level.

After adding a noise level dependence to the model, simulations for the six different time scenarios was completed. Smoothed contours indicating the average number of noise induced/additional awakenings for each scenario are shown in Figure 5. The results are opposite to those found in the ANSI standard. There are more noise-induced awakenings if the majority of aircraft events are at the beginning of the night. This difference is partly due to the time dependent coefficients of the Markov model; for the baseline no-noise model the probability of being in stage wake increases throughout the night, however, for the first and second noise model the probability of being in stage wake decreases with time. This decrease in probability of noise-induced awakenings is supported by other models that have a time dependence (Brink et al. 2008). Overall though the difference in the number of noise-induced awakenings for the different scenarios was small.

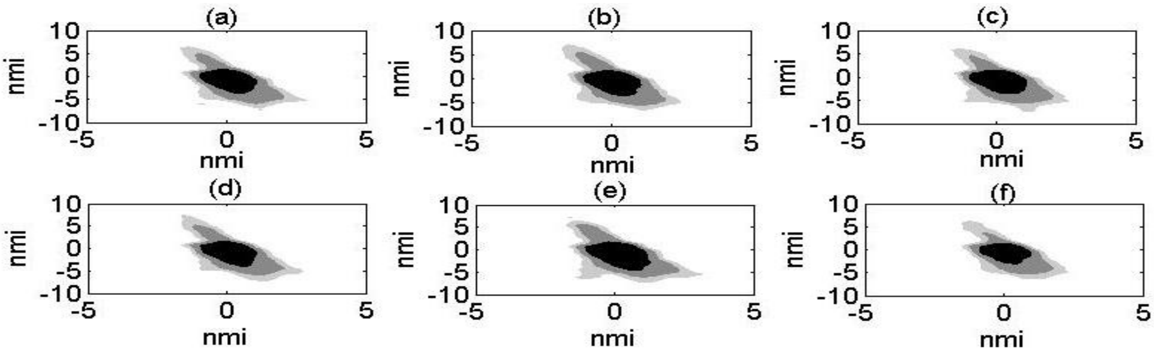


**Figure 5:** Model predictions for Scenario 1 through 6, labelled (a) thru (f), respectively, using Basner's Markov model with level dependence. Gray-scale shading indicates the average number of noise induced awakenings. Black to dark gray 1.5, dark gray to light gray 1.0 and light gray to white 0.5 awakenings.

In addition to differences in the predicted number of awakenings for the different time scenarios, there are also differences in the duration spent in different stages of sleep. A sleep quality index was calculated for the six different time scenarios. This index was developed by Basner (2006) and linearly weights the durations of the different stages of sleep, with Stage 4 having the highest weighting and Stage 2 having the lowest. Therefore, a lower value of the sleep quality index coincides with worse sleep. The differences in values of the sleep quality index for the different time scenarios are shown in Figure 6 and once again are quite small, however the sleep quality index is the lowest for the scenario in which most events are at the beginning of the night as time spent in slow wave sleep is the most affected for this scenario.

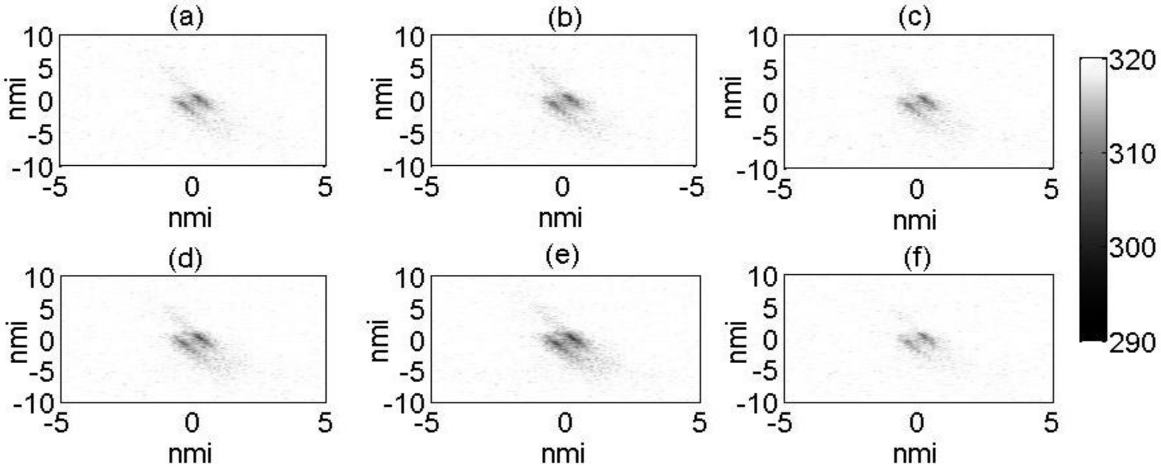


**Figure 6:** Sleep Quality Index for Scenario 1 through 6, labeled (a) thru (f) respectively calculated using Basner's Markov Model with added noise level dependence.

While the changes in sleep structure in the simulations that were conducted are small, predicting these changes does aid in differentiating the impact of different operations scenarios. In addition, most sleep studies have been conducted in healthy populations and it is unknown how much the sleep structure of more vulnerable groups may be affected by noise. Sleep structure models are a useful tool for exa- ,mining the effect of noise on sleep, but there is a need to further develop and validate these types of models.

One aspect of Basner's Markov model that was further examined is the ability to estimate the large number of coefficients of the model, as ideally this model should be further validated using data from other studies. There are 35 coefficients per model and there are four models, one baseline model which is used when there are no noise events and three noise models as it was determined that aircraft noise affects one and a half minutes of sleep. One thousand simulations of Basner's laboratory study consisting of the same number of person-nights (1,008), and number and timing of events were performed in order to determine the ability to re-estimate the coefficients of the model. The coefficients of the simulated datasets were calculated using *mnrfit* in Matlab, which uses an iterative weighted least squares approach for calculating the coefficients. It was found from performing these simulations that several sleep transitions, which are listed in Table 1, never occurred. This is due to certain transitions rarely occurring in normal sleep, for example transitioning from wake directly to stage 4. The coefficients for which there were a nonzero number of transitions could be re-estimated due to sufficient data.

**Table 1:** Sleep stage transitions that did not occur in simulations of Basner's Laboratory Study (0 - 4 wake through stage 4, 5-REM)

| Baseline | 1st Noise Model | 2nd Noise Model | 3rd Noise Model |
|---|---|---|---|
| $s_1$ to $s_4$<br>$s_5$ to $s_4$ | $s_0$ to $s_4$<br>$s_1$ to $s_4$<br>$s_4$ to $s_5$<br>$s_5$ to $s_3$ | $s_0$ to $s_4$<br>$s_1$ to $s_3$<br>$s_1$ to $s_4$<br>$s_4$ to $s_5$<br>$s_5$ to $s_3$<br>$s_5$ to $s_4$ | $s_1$ to $s_4$<br>$s_4$ to $s_1$<br>$s_4$ to $s_5$<br>$s_5$ to $s_3$<br>$s_5$ to $s_4$ |

Due to the number of transitions that do not occur, and the fact that stage 1 is a transition stage and stage 3 and 4 are often combined and referred to as slow wave sleep a reduced model in which there were only four stages (wake, stage 2, slow wave sleep, REM) was created. To calculate the coefficients, simulated datasets were created using Basner's Markov model and then coefficients for a reduced model were calculated based on the simulated datasets. Using the reduced model there were two transitions that never occurred, the transition from REM to slow wave sleep for both the second and third noise model. This suggests that a further reduction of the model should be explored, so that in the future a dependence on noise level as well as other personal or noise characteristics could be added to the model such that the coefficient values could be estimated with an appropriate amount of data.

Another aspect that was examined was the difference in predictions using Basner's Markov model which does not predict the cyclic oscillation between REM and NREM sleep and predictions using a nonlinear dynamic model of sleep which can predict this behavior (Massaquoi & McCarley 1992).

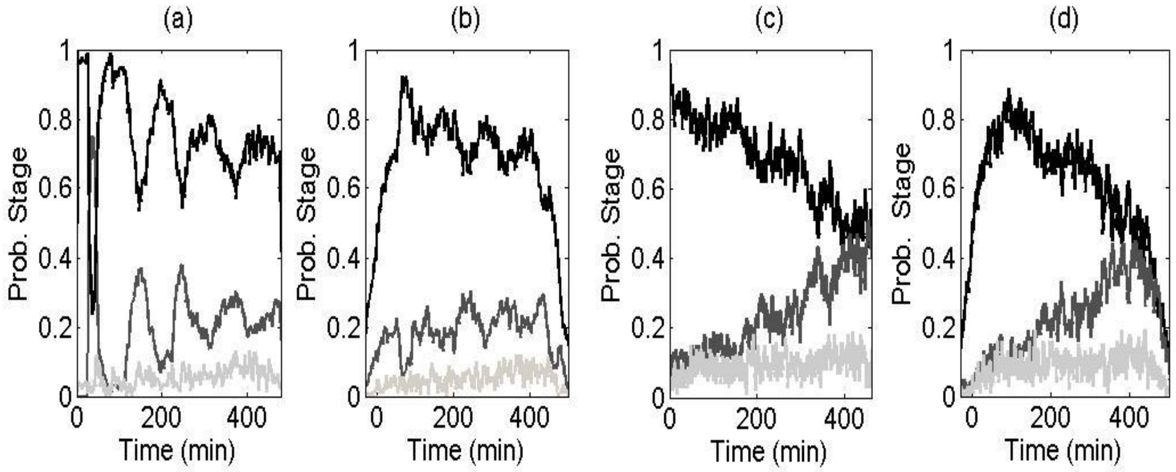


**Figure 7:** Probability of being in NREM sleep (black), REM sleep (dark gray) and Awake (light gray), predicted using (a,b) the Massaquoi and McCarley model and (c,d) Basner's Markov model. (a,c) It was assumed everyone retired to bed at 11:00 pm. (b,d) A Gaussian distribution for time of retiring was assumed with a mean of 11:00 pm and standard deviation of 30 minutes.

One-hundred simulations were performed with both models and the effect of different times of retiring on predicted probabilities of being in different sleep stages were examined. The results are shown in Figure 7. The cyclic nature of time spent in different stages of sleep is largely attenuated when assuming different times of retiring. However, the nonlinear models may still provide useful information on sleep onset latency, and latency to slow wave sleep and REM sleep.

## CONCLUDING REMARKS

The ANSI standard, as it is based on behavioral awakening data, predicts a low number of awakenings compared to other dose-response models, and it was found that this could be problematic when there are a few flights on a specific runway or flying over a specific area. Also the ANSI standard and the Markov model were found to have an opposite dependence on time and therefore have conflicting predictions. The variation in the predictions of number of awakenings and impact on sleep structure for different distributions of events during the night was found to be small. However, before questioning the use of sleep structure models there is a need to examine the change in predictions for a wider variation in flight operations and also the change in sleep for more sensitive populations.

## ACKNOWLEDGMENTS

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# Number of aircraft noise events and motility during sleep

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## ABSTRACT

Both the WHO and the EC advise on the use of $L_{night}$ as the primary indicator for sleep disturbance. Still, a key question for noise policy is whether from a public health point of view it may be advantageous to use number of events in addition to $L_{night}$. For some effects, it may be more effective to reduce the number of events above a certain threshold than to lower the overall exposure level of events. Based on data of a field study among 418 people, the current paper investigates the association between objectively measured sleep disturbance and the number of aircraft noise events. The data from this study are well suited for this purpose, since for every subject both the number and the level of events were available. The analysis focuses on mean motility during the sleep period, and addresses the question whether this motility can be predicted more accurately taking the number of passages into account. The results suggest that an increase in the average sound exposure level of events contributes more to motility than an increase in the number of events. However, it was also found that the influence of number of events increases with increasing levels of the events. Thus, to reduce motility as a proxy for restless sleep, it may be better to prevent the occurrence of events with high maximum levels than to reduce the overall number or level of events.

## INTRODUCTION

Sleep disturbance due to night time noise is a health impact of noise of increasing importance for policy. The recently published WHO Night Noise Guidelines for Europe (WHO 2009) primarily refer to relationships between health and the equivalent noise exposure during the night ($L_{night}$). Both the WHO and the EC (2004) advise on the use of $L_{night}$ as the primary indicator for sleep disturbance. $L_{night}$ can be linked to subjective measures but also to the number of additional awakenings due to nighttime noise (Basner et al. 2010) and motility (Passchier-Vermeer et al. 2002, 2007). However, there are indications that some aspects of sleep disturbance are also dependent on the number, character and distribution of individual noise events over the night (e.g. Basner et al. 2010). A key question for policy is whether equivalent sound limit levels offer sufficient protection against sleep disturbance. In order to answer these questions more insight is needed into the influence of number of events during the night on the degree of sleep disturbance at a given equivalent sound level. Previous analysis on survey data around Schiphol Airport (Miedema et al. 2000) showed that an increase in the number of flights was adequately reflected in the equivalent sound levels as far as annoyance was concerned. However, for sleep disturbance this could be different. Theoretically, given a certain equivalent level, the maximum level of disturbance should take place at $L_{Amax}$ or SEL levels close to the threshold level for a specific indicator of sleep disturbance (EC 2004).

While an association between $L_{Aeq}$ or $L_{night}$ has been established for subjective sleep disturbance, mean motility and number of awakenings, $L_{Amax}$ and *SEL* of individual events may be more predictive of instantaneous and short term effects such as (onset of) motility, awakening, cardiovascular responses and sleep stage changes (WHO 2009). Therefore, in principle the prediction of effects such as mean motility and number of awakenings may be improved by additional information on the number (combined with levels) of individual events. Based on a field study among 418 people, Passchier-Vermeer et al. (2002) presented relationships between night-time aircraft noise exposure and motility for three time scales (instantaneous levels, sleep period and long term). Both *SEL* and $L_{Amax}$ of aircraft noise events as measured inside the bedroom were found to be related to instantaneous (onset of) motility (measured by actimetry), and behavioral awakening (button push). Also, mean motility over a sleep period as measured by actimetry was shown to be associated with $L_{Aeq}$, while long term mean motility was associated with $L_{night}$. Furthermore, mean motility (both per night and over longer periods) was positively associated with indicators of subjective sleep quality and/or perceived awakenings, health complaints and adverse sleep effects.

Taking these findings as a point of departure this paper investigates the association between objectively measured aspects of sleep disturbance and the number of the individual noise events, based on the available data from the field study of Passchier-Vermeer et al. (2002). The data from this study are well suited for the present purpose, since for every subject aircraft noise exposure was measured inside the bedroom for several nights, on the basis of which both the number and the level of events could be derived. Furthermore, both subjective and objective measures of sleep disturbance were collected. The analysis focuses on mean motility during the sleep period, and addresses the question whether this motility can be predicted more accurately taking the number of passages into account.

## METHODS

### Data

As part of the health impact assessment around Schiphol airport commissioned by the Netherlands Ministry of Housing, Spatial Planning and the Environment and in close collaboration with the Netherlands Institute for Public Health and the Environment (RIVM), a study was performed among 418 adults residing at various distances from Schiphol airport. The objective of the total study was to derive dose response relationships for night time noise effects and to estimate the prevalence of noise related sleeping disorders at a population level.

### Respondents

Candidates for participation in the study were recruited by mail. The request to participate and a leaflet with information about the study were sent to 3,000 addresses. About 540 candidates showed interest in participating, 440 of which were selected for an intake visit and further consultation, and 418 subjects decided to take part in the study. All 418 subjects that actually started participation completed the study, for which they received a small remuneration. Subjects participated from a Monday evening until a Friday morning 11 days later. During this period, they wore an actimeter (CNT, type AW4, weight about 50 grams) monitoring body movements continuously, with the exception of periods of bathing and swimming. In addition, they filled out an extensive questionnaire at the start of the study, they filled out a morning and evening diary, as well as a sleepiness scale during day and evening (five times). The subjects in this study were exposed to usual night-time aircraft noise in their bedroom. Ages varied between 18 and 81 years, 50 % of the subjects were male, 6 % lived less than 1 year in the present neighborhood, 44 % were over 15 years and the remaining 50 % between 1 and 15 years.

### Locations

The study was carried out successively at 15 locations within a distance of 20 km from Schiphol, selected mainly on the basis of modeled nighttime (23h-06h) aircraft noise exposure. Other selection criteria pertained to road and railway noise, degree of urbanization and type of dwelling. Two locations were selected because of their presumed absence of nighttime aircraft noise. The other locations had various degrees of nighttime aircraft noise exposure, from relatively few aircraft at night up to the highest exposure in residential areas close to Schiphol Airport. At each location, data were collected during two subsequent intervals of 11 nights. Valid data are available for 414 respondents, with a maximum of 11 nights. In total, exposure measures and sleep characteristics were collected during 4,048 respondent-nights.

### Sleep disturbance measures

Motility is the term used for accelerations of the body or body parts during movements. It is measured with actimeters, usually worn on the wrist in field research, detecting whether movement has or has not taken place during a specified interval (in this study, the sample rate was 15 s). Actimetry has been used in the last decade to monitor sleep disturbance in large field studies with subjects sleeping at home exposed to the usual aircraft, road traffic or railway noise (Ollerhead et al. 1992; Horne et al. 1994; Fidell et al. 1995, 1998; Griefahn et al. 1999; Passchier-Vermeer et al. 2002). For this particular analysis, the mean probability of motility was derived based on all 15 s intervals within one sleep period time. In addition, self-reported sleep quality was used, measured with a question in the morning diary. The wording of the question was: 'How well did you sleep last night?', with extreme answering categories labeled: 0=very bad, 10=very well. This 11-point scale was recoded into a 0-100 scale where 0 means good and 100 means bad sleep quality.

### Noise exposure measures

To assess night-time aircraft noise exposure of subjects, noise measurements were performed from 22-9h with indoor noise monitors in the bedroom of each subject and with one outdoor noise monitor. For each second, the noise monitors stored the equivalent sound level. Aircraft noise events were identified by comparing the noise and time data stored in the indoor and outdoor noise monitors with information obtained from the aircraft identification system at Schiphol (FANOMOS).

### Statistical analyses

Although the method previously described and used by Miedema et al. (2000) is in principle very appropriate to quantify the trade-off between number of events and sound level, this analysis did not give reliable estimates for the trade-off parameters, because the relationship between exposure level during the sleep period and mean motility was not strong enough for a stable optimization of the parameters. Therefore, following earlier studies (Fields 1984; Vogt 2005), the relative impact of the noise level L of events and the number N of its average daily occurrence on the variable of interest (Y) was expressed as the ratio of regression coefficients BN/BL taken from:

$$Y = B_0 + B_L L + B_N \log N + B_t \log (\Delta t / T) + B_i X_i$$

where $\Delta t$ is the average duration of the noise events for a night and T the total sleep time for a night. $B_0$ and $B_L$ are the regression coefficients for number and sound exposure level (SEL) of a noise event, respectively. The ratio between the two ($k = B_N / B_L$) indicates the relative importance of number compared to level, and is called the decibel-equivalent number effect. It equals 10 in the equal-energy indices (e.g. Leq), because a tenfold increase in number corresponds to a 10 dB increase in level. $B_i X_i$ are additional variables of interest.

To predict mean motility during a sleep period time, linear regression models were built in a stepwise manner, starting from the overall mean to a final model predicting motility from the average sound exposure level as well as the number of aircraft passages, controlling for sleep time, average duration of events, age and gender. Sleep time was included in the model to adjust for the fact that a longer sleep period may be associated with increased mean motility, regardless of the number of aircraft passages. The other control variables were chosen on the basis of earlier studies, indicating that effects of age (Passchier-Vermeer et al. 2002) and gender (Reyner et al. 1995) are to be expected. To account for highly correlated observations within persons, respondent ID was treated as a random factor in the model.

## RESULTS

Motility during the sleep period proved to be positively related to both indoor sound exposure levels and to the number of events, although number of events no longer contributed significantly when controlling for age and gender of the subject. Age had a curvilinear effect, with the lowest motility for respondents aged between 40 and 50, while gender had no effect on motility. Furthermore, a decrease in subjective sleep quality was found to be positively associated with indoor sound exposure levels, but not significantly with the number of events, and females overall proved to have decreased subjective sleep quality as compared to males. The equivalent rise in sound exposure levels to the hypothetical case of a tenfold increase in the number of passages was estimated by the decibel-equivalent number effect *k*, defined as the ratio between the estimates for the number and for the level effect. This proved to be around 5 for the prediction of motility in the unadjusted model, meaning that doubling the number of aircraft passages is equivalent to a 1.50 dB increase in average sound exposure level. For the prediction of bad subjective sleep quality, *k* was found to be 3.5 in the unadjusted model, meaning that doubling of number of aircraft passages is equivalent to a 1.07 dB increase in average sound exposure level.

## CONCLUSIONS

The present results suggest that, over the whole range of exposure in the present dataset, an increase in the average sound exposure level of events contributes more to motility and to subjective sleep quality than an increase in the number of events. However, in a posthoc descriptive analysis indications were also found that, given a certain $L_{Aeq}$ level, the number of events has relatively little influence when all events are taken into account, but that the influence of number of events increases with increasing levels of the events. Thus, to reduce motility as a proxy for restless sleep, it may be better to prevent the occurrence of events with high maximum levels than to reduce the overall number or level of events.

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# An event-related examination of awakenings due to nocturnal church bell sounds

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## ABSTRACT

We carried out a a field study to elucidate whether acoustic properties of nightly church bell ringing events systematically relate to awakening reactions. Results indicate that the bell ringing events increase awakenings in a similar fashion as has previously been reported with transportation noise events (aircraft, railways) and that awakening probability first and foremost depends on maximum sound pressure level of an event.

## INTRODUCTION

Only very little knowledge exists about the sleep disturbing effects of nocturnal ambient non-traffic related noise such as noises from the neighborhood, slamming (car-)doors, noises from restaurants and bars, or bell strokes emitted from bell towers (Omlin et al. 2011). Unlike many other christian countries, in Switzerland an estimated half of all churches in the country, mainly protestant, ring their bells to indicate the time also throughout the night, which not only surprises foreign visitors now and then, but is suspected to cause sleep disturbances in a small, but qualified minority of the population. Church bells therefore were brought into focus of noise regulation policy. On the background of activation-theoretical aspects of sound perception, it is evident that because of the specific characteristics of church bells (high impulsivity and tonality), rating procedures developed for other noise types cannot easily and reliably be applied to this type of source. We therefore carried out a field study to determine the effect of nocturnal church bell ringing and bell strokes on awakening reactions of residents that live near churches. In the field study, awakening reactions due to church bell sounds were determined using portable polysomnography (PSG) in the customary sleeping quarters of voluntary subjects. They all lived in close vicinity of a bell tower that throughout the night indicates the time with bell strokes and rings the bells to herald masses or church services in the early morning.

The research goals of the study were to elucidate whether acoustic properties of bell stroke noise events systematically relate to a particular probability to awake and to provide exposure-effect functions between acoustical predictors and the probability of awakening.

## METHODS

The basic study protocol can be paraphrased as "event-related investigation of sleep stage changes that are elicited by bell strokes from church bell towers during the night". An event-related analysis establishes a direct temporal association between the occurrence of noise events and the reactions of the sleeper to such events. In the present study, 30 subjects living near church bell towers were polysomnographically measured, each for four nights with the first night as an adaptation night to avoid a "first night effect" (Agnew et al. 1966; Mendels & Hawkins 1967). Awakenings were defined as the transition from any stage of sleep (S2, S3, S4, or REM) to the wake (W) or S1 stage, objectified from sleep profiles. Besides the polysomnographic measurements, the sound signal both inside the bedroom (near the ear of the sleeper) as well as outside on the building façade was recorded. Subjects were visited by one or two investigators each evening preceding a recording night where acoustic recording equipment was installed and subjects were prepared for the PSG recordings. Subjects were paid a remuneration of 200 CHF upon completion of the study.

### Sampling of churches and subjects

The recruitment of subjects was conducted through random mail order at 9 preselected locations (churches) within or in close vicinity to the city of Zurich. Two sample strata were considered according to radial distance from the bell tower (0-100 m, and 100-200 m). About an equal number of addresses within the 100 m radius and within the 100-200 m ring were contacted. Potential subjects underwent a pre-screening where their hearing ability was tested with audiometry. Each person definitely interested in taking part was subjected to a screening night, where he/she was checked for excessive snoring or indications of sleep apnea. Such candidates were excluded. Study participants who, during the measurements, showed a possibly medically relevant deviation from normal sleep were also excluded from the sample and they were informed of the suspicion and recommended to see a specialist.

### Acoustic measurements

In each experimental night, the ambient sound was continuously recorded on two channels (one indoor, one outdoor) with high-end portable digital audio recorders. During the on-site equipment setup, each night, a calibration tone of 1.000 Hz emitting 94 dB was recorded on both channels. The recording resolution on each channel was set to 44.1 kHz sampling frequency and 16 bit sample resolution (i.e. the CD standard), creating about 2.5 Gigabytes of sound data per channel per night. Concurrently, on a third audio channel, the DCF77 (callsign) long wave time signal was recorded using a DCF77 receiver. The time signal ensured that exact absolute timing of the recorded bell stroke events could be achieved at any point in time of a night's sound recording. All signals were recorded onto CompactFlash memory cards and stored as normal (PCM) wave files. All further acoustic processing was done offline. The outdoor microphone was attached with Gaffa tape on the outer face of the bedroom window. The indoor microphone was placed as closely as possible to the assumed position of the head of the sleeper. The DCF77 receiver was placed on a small tripod in a convenient place. During all measurements, subjects were required to keep the bedroom window(s) open or half-open.

## Polysomnographic (PSG) measurements

With portable polysomnographic recorders, the electroencephalogram (EEG), electrooculogram (EOG), electromyogram (EMG), electrocardiogram (ECG), respiratory movements, finger pulse amplitude and position in bed were recorded continuously during the night. To derive the polysomnogram (sleep profile), each experimental night was divided into 30s-epochs. Before each PSG recording, the recorder's internal clock was electronically synchronized with the audio recordings using the DCF77 time signal receiver. To mark the beginning of the sleep period, subjects were required to press a marker button on the recorder when they switched off the lights and wanted to sleep. As validation studies on various automated sleep analysis systems have reached contradictory conclusions (Caffarel et al. 2006), we decided for a visual scoring of sleep stages. Two trained scorers independently assigned sleep stages in every 30s-epoch according to the Rechtschaffen & Kales manual (1968). The nights to analyze were allocated randomly, but at least one night of each subject to each scorer.

## Event-related analysis of awakening reactions

For an analysis of awakening reactions, all relevant noise events in a night need to be related to the progressing sleep epochs (or vice-versa) and for each noise event, it is to be recorded, whether the subject did awake during or after the event. To be considered to be related to a noise event (or caused by it, for a discussion of causation see Brink et al. (2009)), awakenings must take place within a time window of certain duration, usually covering a few epochs after the noise event started. In order to assign a sequence of sleep stages to each event (e.g. "222W11"), in a first step, for each recorded night, all relevant church bell noise events were identified by human listeners. The acoustic offline processing delivered, for each event, two wave files of the original microphone signals (in- and outdoor), as well as diverse exposure metrics. Each noise event could be characterized by (1) its starting time, (2) its duration, (3) its type of ringing (quarter-hour, full-hour), (4) its number of bell strokes, (5) its acoustic parameters, such as $L_{AF,max}$ etc. For each noise event with its exactly defined start- and endpoint, a sequence of sleep epochs was extracted from the respective sleep profile. This sequence comprised the epoch preceding the start of the event, the epoch within which the event started, the epoch when the event ended (often the same as the starting epoch), all epochs between (if applicable), and four further epochs after the epoch, when the event ended. Awakenings were assigned to those noise events, where the subject was in a stage of sleep (S2-S4 or REM) in the preceding epoch and changed to a stage of wakefulness in either the starting epoch or any epoch thereafter.

The analyses account for so called *additional awakening reactions*. These are those awakenings, where the noise event is the sole and only possible reason for an observed awakening and $P_{AWR,additional}$, the probability of an additional awakening reaction is thus the indicator of most practical interest. A profound discussion of awakening probability calculation is provided in Brink et al. (2009).

## Statistical procedures

Awakening probability due to acoustic characteristics of church bell sounds was modeled using random effect logistic regression analysis. In all model definitions, subjects were treated as random intercept effect. The slopes of the effects of acoustic parameters (e.g. $L_{AF,max}$) on awakening probability were assumed constant across subjects.

RESULTS

## Sample characteristics

30 people in the neighborhood of 9 different churches were measured within the 5 months of the field study period. 3 subjects had to be excluded during the study as they showed symptoms of sleep apnea or excessive snoring which were not detected beforehand. This resulted in a sample of 27 subjects of which 15 (55.6 %) were female and 12 (44.4 %) male. 8 subjects were aged between 18 and 33 years, 10 between 34 and 49 years, 8 between 50 and 65 years and 1 subject was 66 years old. The mean age was 41 years.

## Noise events

The indication of time (ringings) at all investigated churches was composed of either a sequence of quarter-hour bell strokes representing 15 (1 stroke), 30 (2 strokes), or 45 (3 strokes) minutes after a full hour, or full hour ringings that are always preluded by 4 quarter-hour strokes and followed by the respective number of full hour bell strokes, usually by a bell with a lower tone. For practical reasons we decided that single bell strokes should not be considered independent events, but that any sequence of strokes being part of one time indication should be treated as one single ringing event. Although the study normally ran for four nights for each subject, the (first) adaptation night was disregarded in the analysis. In total, 81 nights (excluding adaptation nights) were analyzed from 27 subjects which were validly recorded during 5 nights (2 subjects), 3 nights (22 subjects), 2 nights (2 subjects), or 1 night (1 subject) respectively. Within these 81 valid nights, 1,738 church bell events were determined which laid within the sleeping periods of the subjects, and for which valid polysomnographic records and valid acoustic data were available. Of these, for 421 events, the sleeper was in the W or S1 stage prior to the event. These events could thus not be used for the analysis of awakenings. On average, 23 church bell events per night could be analyzed.

Figure 1 displays the frequency distribution of the maximum sound pressure levels of church bell noise events both at the indoor and outdoor microphone.

## Event-related analysis of awakening probability

In order to determine optimal time window duration, i.e. to maximize the probability of additional awakenings, we adopted the suggestions in Brink et al. (2009) and came to the conclusion, that a 2 epoch long time window (60 s) catches most of the awakening effect. The inferential analyses in the present paper are thus based on a 60 s time window and an assumed spontaneous awakening probability ($P_{AWR,spont}$) of 0.066 – which was determined during noise-free time windows.

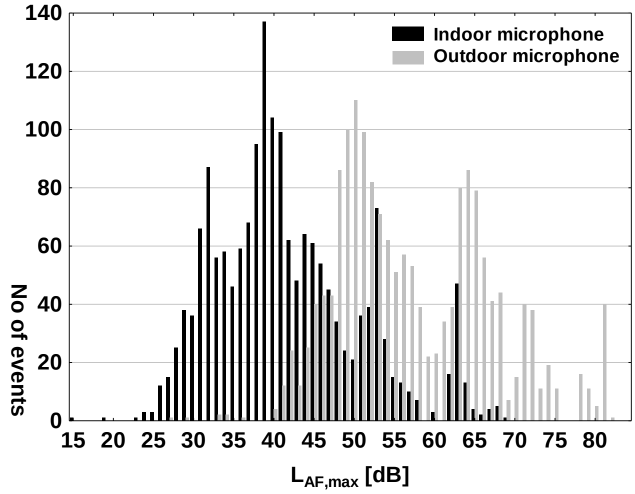


**Figure 1:** Frequency distribution of the maximum sound pressure levels of church bell noise events

### Hierarchical logistic regression on $L_{AF,max}$, background sound level, and sleep-related predictors

The probability to awake basically changes continuously as sleep advances. One can expect that awakening occurs more easily at the end of the night than at its beginning and that deeper sleep stages are less prone for awakening from environmental stimuli than light sleep (Basner et al. 2011). Therefore we regressed awakening probability on maximum sound pressure level and sleep-related predictors that were suggested by Basner et al. (2006) pertaining to awakening probability from aircraft noise events. This model contains the maximum A-weighted sound pressure level ($L_{AF,max}$), the background noise level in the minute preceding the bell stroke event ($L_{Aeq,\ 60\ seconds}$) as well as their interaction term ($L_{AF,max} \times L_{Aeq,\ 60\ seconds}$), furthermore the number of epochs that passed since sleep onset and the binary dummy variables SWS stage in the previous epoch (1=S3 or S4, 0=all other stages), and REM stage in the previous epoch (1=REM, 0=all other stages). The model coefficients are listed in Table 1.

The logistic functions provided by the multivariate model in Table 1, including confidence intervals for the prediction of awakening probability, are plotted in Figure 2, assuming (as in Basner et al. 2006) a 27.1 dB(A) background level, prior sleep stage to be S2 and time since sleep onset to be 601 epochs. These specifications correspond to a relatively sensitive sleep situation and were chosen for preventive reasons, i.e. to rather over- than underestimate the noise effect. As expected, the probability to awake increases with $L_{AF,max}$ of church bell noise events, with background noise level, as well as with elapsed sleep time – although not all parameters are significant, their behavior more or less is in line with previous findings with other noise sources like aircraft (Basner et al. 2006) and railways (Müller 2010) except that in the present study, the REM stage revealed to be the least sensitive sleep stage. Awakening probability is negatively related to slow wave (S3 and S4) and REM sleep compared to S2 sleep. The statistically relevant increase of awakening probability begins at about 30 dB maximum sound pressure level.

**Table 1:** Coefficients of a multivariate hierarchical logistic regression model for observed awakening probability (60 s time window) explained by acoustic and sleep-related predictors [Model based on N=1,322 events]

| Effect | B | SE | df | t | p |
|---|---|---|---|---|---|
| Intercept | -7.9605 | 2.3430 | 27 | -3.3975 | 0.0021 |
| $L_{AF,max}$ indoors | 0.1312 | 0.0515 | 27 | 2.5494 | 0.0168 |
| Background level $L_{Aeq, 60\ seconds}$ | 0.1283 | 0.0824 | 27 | 1.5571 | 0.1311 |
| $L_{AF,max} \times L_{Aeq, 60\ seconds}$ | -0.0028 | 0.0018 | 27 | -1.5244 | 0.1390 |
| Epochs passed since sleep onset | 0.0004 | 0.0004 | 27 | 1.1678 | 0.2531 |
| SWS stage preceding epoch (1=yes) | -0.2430 | 0.3170 | 27 | -0.7665 | 0.4500 |
| REM stage preceding epoch (1=yes) | -0.4633 | 0.2060 | 27 | -2.2489 | 0.0329 |

Could the awakening potential of church bells be compared to that of other noise types? Though a legitimate question, comparing awakening probability functions from different studies is a very difficult task. Mostly because the methodologies and the type of measurement of the relevant outcome "awakening" as well as differences in the degree of controlling for confounders and dissimilarities of noise exposure conditions in the laboratory and within real life settings and often questionable representativity severely hamper the ability to rank order the findings from different studies/noise sources in terms of their potential to evoke awakening reactions. Any comparison must therefore take place with greatest possible care.

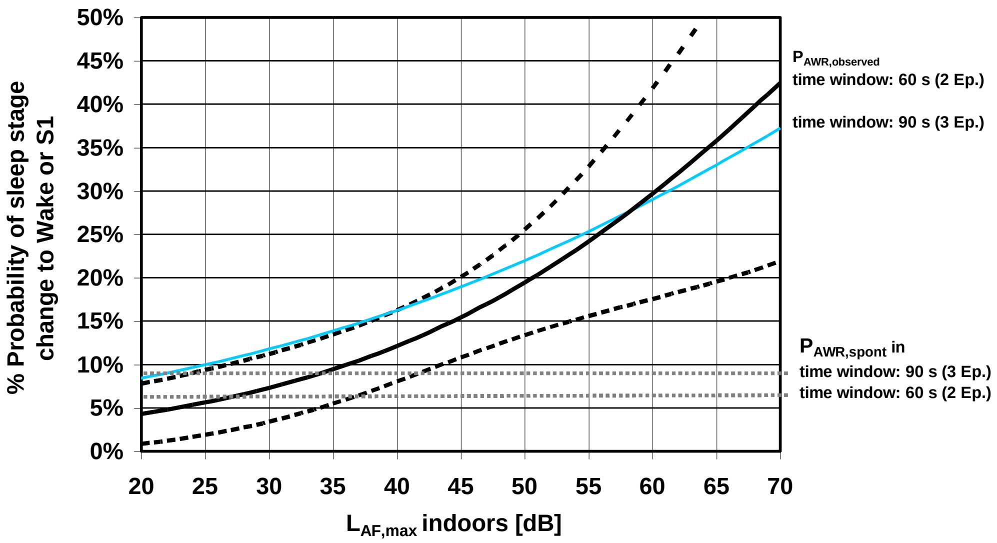


**Figure 2:** Probability ($P_{AWR,observed}$) of sleep stage change to S1 or W (wake) depending on maximum indoor sound pressure level of church bell noise events, based on a 60 second time window (thick black curve) with +/- 95% confidence intervals (dashed curves). For information, the curve modeled for a 90 second (3 epochs) time window is shown also. Spontaneous awakening probability ($P_{AWR,spont}$) is represented by dashed grey lines. Assumptions: Background noise level: 27.1 dB; Prior sleep stage: S2; Epochs passed since sleep onset: 601 epochs (5 hours).

Figure 3 contrasts the exposure-awakening relationship for church bell noise events in the current study with that for aircraft noise events derived in the large study of the DLR (Laboratory study: Basner et al. 2004; Field study: Basner et al. 2006), with the curves derived from the meta-analysis of Pearsons et al. (1995), and the Vos & Houben study on sleep disturbance caused by impulse sounds (shown is the curve for a single "door slam") (Vos & Houben 2007).

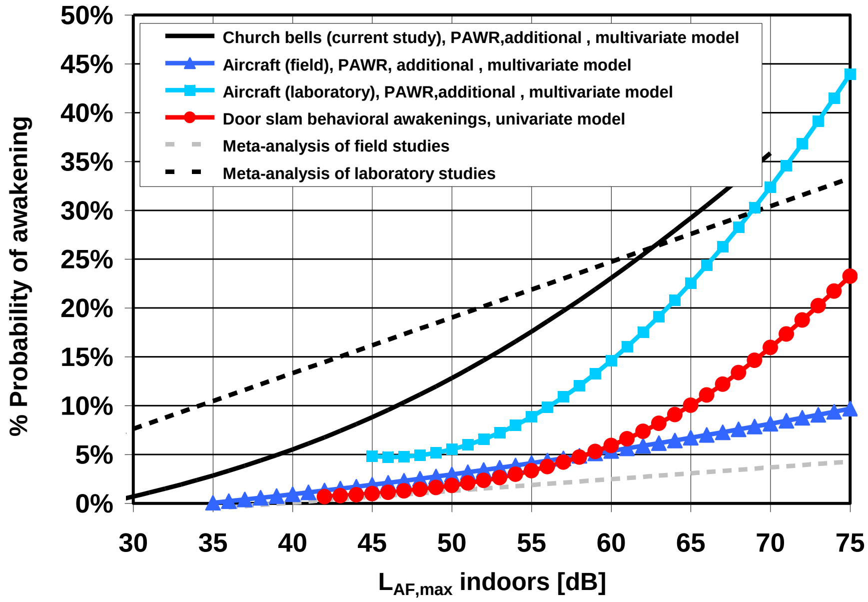


**Figure 3:** Comparison of exposure-response relationships of the probability of awakening reactions as a function of the (indoor) $L_{AF,max}$ sound pressure level in the current study with curves of other noise sources (Basner et al. 2006, 2004; Pearsons et al. 1995; Vos & Houben 2007). The curves for church bells and aircraft account for the additional awakening probability at 601 epochs after sleep onset and a background noise level of 27.1 dB(A). The sleep stage prior to the event was assumed to be stage S2. Conversion used: As the original models for aircraft (Basner et al. 2006, 2004) were based on the SLOW time constant, the curves for aircraft were shifted by 2 dB, an offset that corresponds to the estimated average difference between FAST and SLOW measurements of typical aircraft noise events

The exposure-awakening functions from different studies, as depicted in Figure 3, are more or less shifted from each other and also display different slopes. While the curves differ quite considerably regarding the horizontal shift, expressible in Decibels, the awakening probability in the exposure range of most practical interest, namely $L_{AF,max}$ values between about 30 and 75 dB, rises from zero to just about 40 %. Church bell ringing events lead to an increase of awakenings in a similar fashion as aircraft noise events in a laboratory setting do, but apparently somewhat more strongly compared to other noise sources in field settings.

## CONCLUDING REMARKS

Results indicate that nightly bell ringing events increase awakenings in a more or less similar fashion as has previously been reported with transportation noise events and that awakening probability basically depends on maximum sound pressure level whereas the other investigated predictors play less important a role. The statistically relevant threshold for an increase of awakening probability as a function of maximum sound pressure level starts at the point where additional awakening probability equals the spontaneous probability to awake. In the current study, this point can be located at about 30 dB $L_{AF,max}$ (cp. Figure 2). Compared to previous research pertaining to other sources, the exposure-effect function for church bells and awakening probability is quite steep – church bells seem to trigger awakening reactions much more easily than aircraft. Possible reasons for such a difference could be the higher impulsiveness and tonality of church bell sounds.

A planned follow-up analysis based on the same sample's acoustic and PSG-recordings will elucidate in more detail how the current results for church bells compare to the awakening probability of other noise sources that were recorded as well (traffic noise, noises from inside or outside the house or from neighbors etc.).

### Acknowledgements

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# Sleep times, sleep quality and subjectively perceived disturbing noise sources in a representative sample of the Swiss population

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## INTRODUCTION

Sleep phase preference and social demands such as working hours can considerably differ among people. However, the physiologically driven sleep phase preference, controlled by an endogenous pacemaker in the brain, remains nocturnal in humans independent of social and other demands. Thus, it is of crucial importance for daytime functioning that sleep at night is not disturbed by environmental factors such as noise. We conducted a survey to provide data representative of the Swiss population on habitual sleep times and on different environmental noise sources that disturb sleep in order to determine at what time most people sleep so that this time can be considered as “night” which needs appropriate protection against noise disturbances. This is of urgent importance, since the population around the national airports has been complaining of being awakened by aircraft noise in the morning between 6 and 7, which according to Swiss regulation refers to as “daytime”.

The current Swiss regulation has limit values for a range of environmental noise sources for day- and nighttime separately. To add to the complexity, the start time of a day and night episode depends on the various noise sources, but are currently not based on the sleeping habits of the Swiss population. Furthermore, the defined times of day and night episodes are the same for workdays and weekends although, due to societal constraints, most people sleep at rather different times on free days and workdays (Borbély 1984; Roenneberg et al. 2003; Groeger et al. 2004).

Based on the above mentioned important shortcomings in the current Swiss protection ordinance, we conducted a survey in a representative sample of the Swiss population and addressed the following five main questions:

- At what time do people sleep during work and free days?
- Is there an age-related change in preferred sleep times?
- Which are the noise sources responsible for noise-related sleep disturbances?
- Does noise annoyance relate to the objectively modeled noise exposure?
- Does sensitivity to noise relate to objectively modeled noise exposure and subjective sleep quality?

The results will be discussed in the context of the regulatory question about Swiss day and nighttime limits.

## METHODS

### Survey procedure and sampling

In February 2011, 2,009 Swiss residents aged 12 years and older living in a household with a registered fixed network who could be surveyed either in French, German or Italian were interviewed by means of CATI (computer assisted telephone interview). The survey was conducted by the LINK Institute, Lucerne, from the laboratories in Zurich, Lausanne and Lugano using a telephone interviewing program. A random quota sampling, directed by a computer assisted sample organizer program, was used. The sampling procedure within a region comprised two stages: first a household was chosen at random in the phone directory then the person was chosen according to a quota sampling. The quotas were based on the age, gender and working status of the structural data for the Swiss population in 2008-2009 according to the Federal Statistical Office (FSO).

In order to have sufficient data in all 3 regions, the number of interviews was disproportionate to the population. To account for this, the data were weighted in the analyses. The mean duration of an interview was 20.6 minutes.

Children are rarely included in surveys because it is rather difficult to interview them. Furthermore, up to the age of 10 years the bed- and rise times are usually determined by the parents. In our survey, we interviewed persons from the age of 12 years on, and we will complete the sleep time data for the younger children with the data set gathered by the Zurich Longitudinal Studies (Iglowstein et al. 2003). These studies included 493 children followed from birth to the age of 16 years in 3 separate cohorts from the Zurich area, which formed a representative selection of the Swiss urban population (Iglowstein et al. 2003).

### Questionnaire

The questionnaire comprised questions on health and use of remedies, sleep habits, sleep disturbances and sources of disturbing noise sources; included were the questions of the 1984 survey (Borbély 1984), the Munich Chronotype Questionnaire (Roenneberg et al. 2003) and the short form of a noise sensitivity questionnaire (Zimmer & Ellermeier 1998). The questions were adapted for telephone interviews in Swiss German and translated into French and Italian.

Sleep and wake-up time were assessed with the following specific question: 'when are you ready to sleep' and not 'when are you going to bed' and 'when do you wake up' and not 'when do you get up'. Thus, here we aimed at gathering people's actual sleep times instead of bedtime, which was asked additionally considered in a separate question.

### Objective traffic noise data

We used the objective noise data of the Swiss noise database sonBase (FOEN 2009a, b), which maps the traffic noise of the entire country on a scale of 10 x 10 meters with the number of people exposed to noise. SonBase provides data based on the vectorised 1:25,000 national map issued by the Federal Office of Topography swisstopo (vector 25). The objective noise level is the rating level (Lr) in dBA. As expected not all interviewees accepted to provide their exact address. Nevertheless, we were able to receive objective noise measures in 1,458 people, for whose address location a reliable validation of noise emission was possible.

### Data analyses and statistics

For each question, we first tested whether the answer distribution between subsets was different from the distribution of the whole dataset by means of a Chi-square test. The means of subsets were tested by T-tests. For the relation between subjective and objective traffic noise measures, Spearman's Rank correlations were calculated.

RESULTS

**At what time do people sleep during work and free days?**

Figure 1 shows the distribution of sleep times on work days and free days for persons aged 12 and more. On work days, the first quartile of sleeping time was at 22:30, the median at 23:00 and the upper quartile at 23:00. On free days, there was a general shift to later times 23:00, 23:45 and 00:30 respectively. On work days, the first quartile of wake up times was at 06:00, the median at 06:30 and the upper quartile at 07:00. On free days, these times delayed to 07:00, 08:00 and 09:00, respectively. This delay shift on free days was much more pronounced for the wakeup- than the sleep times.

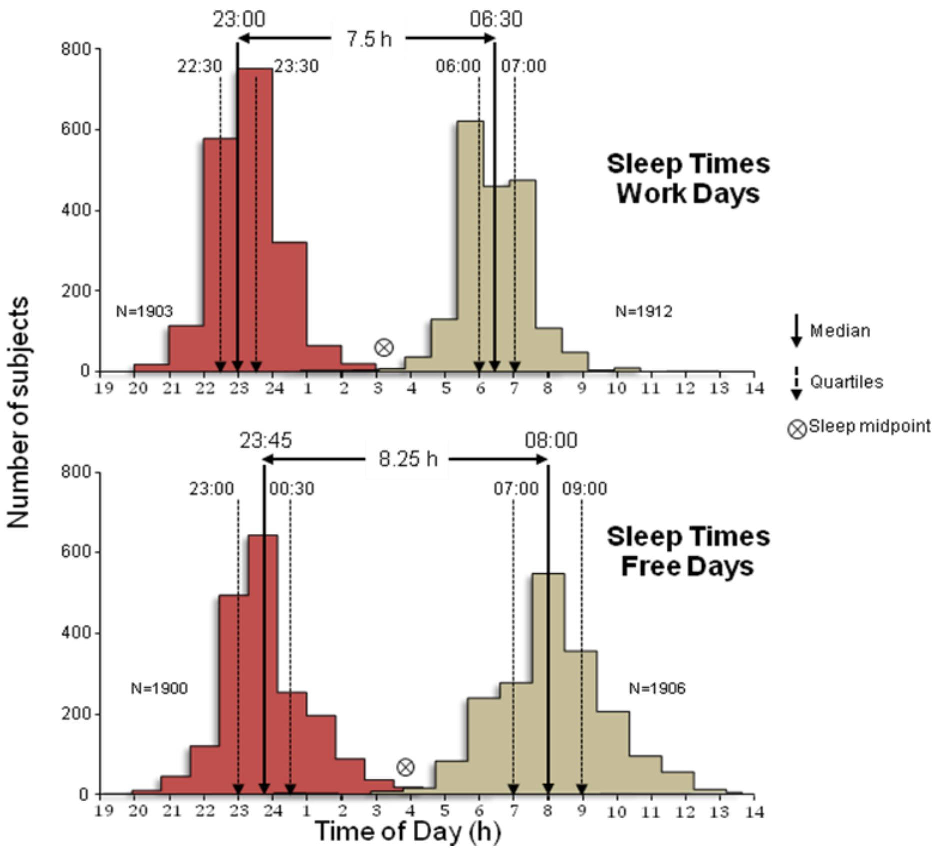


**Figure 1**: Sleep times in a representative sample of the Swiss population

**Is there an age-related change in preferred sleep times?**

Figure 2 shows the age-related changes in the sleep times on work days and free days separately for persons aged 12 and more. The median and lower quartile of sleep times on work days were remarkably stable from the age of 16 on with a slight trend towards later times with age in contrast to the ones on week-ends that were latest for the age of 16 to 19 and then became earlier with increasing age, finally approaching the times for work days at the age of 70. The median wake-up time on work days was rather stable across ages with earliest wake-up times for the 40 to 59 years old people whereas the upper quartile tended to become later across ages. The most striking effect of age represented the wake-up times on weekends with median wakeup times being latest for the 12 to 19 years old people and advancing by one hour per decade between 20 and 39 followed by a slower rate until the earliest time is reached in oldest persons. The upper quartile became later from 12 to 19 where it was at its latest at twelve o'clock and then advanced to an earlier time more or less like the median.

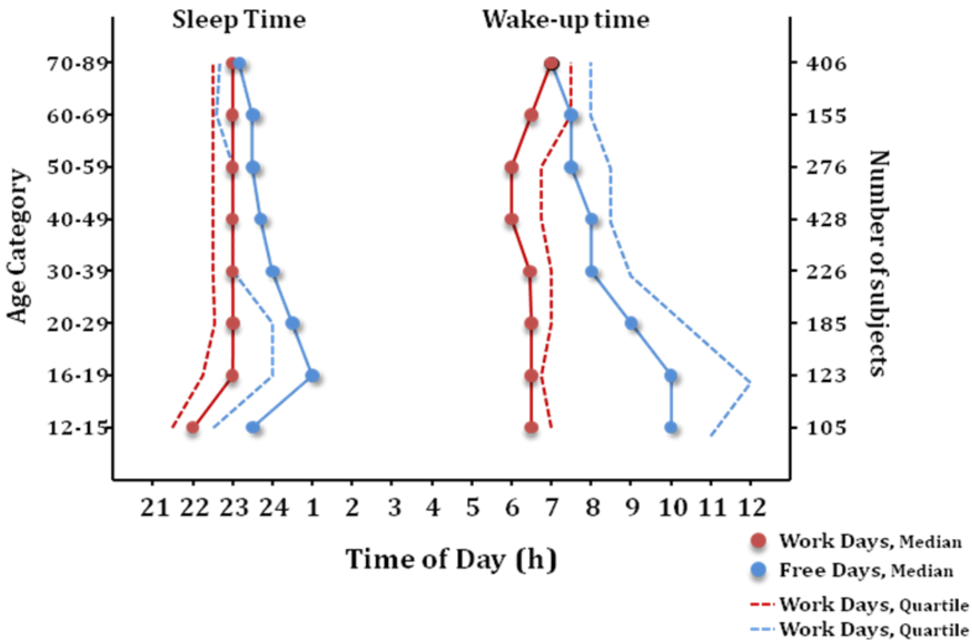


**Figure 2**: Age-related changes in sleep times in a representative sample of the Swiss population

## Which are the noise sources responsible for noise-related sleep disturbances?

The noise sources, which awakened people, hindered them to fall asleep or get back to sleep, are listed in descending order in Table 1. For the ranking, the answers 'very often' were weighed by a factor of 4, 'often' of 3, 'occasionally' of 2 and 'seldom' was taken unchanged and then added to a score for each noise source.

**Table 1:** Answers (in %) to the question 'when sleeping badly are you awakened or hindered to fall asleep by one of the following sounds?'

| | Very often | Often | Occasionally | Seldom | Never | Score |
|---|---|---|---|---|---|---|
| Children or pets | 2.2 | 5.8 | 12.9 | 13.8 | 65.0 | 65.8 |
| Road traffic | 1.3 | 3.9 | 12.9 | 13.4 | 68.3 | 56.1 |
| Neighbors | 0.6 | 2.8 | 8.6 | 16.7 | 71.1 | 44.7 |
| Restaurants, music, events | 0.5 | 1.4 | 5.9 | 13.6 | 78.4 | 31.6 |
| Church bells | 1.2 | 1.9 | 6.0 | 7.8 | 83.0 | 30.3 |
| Aircraft | 0.9 | 1.6 | 5.7 | 9.6 | 82.0 | 29.4 |
| Rail | 0.5 | 0.9 | 5.5 | 6.1 | 86.7 | 21.8 |
| Cow bells | 0.3 | 0.4 | 2.3 | 4.3 | 92.5 | 11.3 |
| Industry | 0.2 | 0.6 | 1.2 | 2.5 | 95.1 | 7.5 |
| Frog croaking | 0.2 | 0.2 | 1.2 | 2.2 | 96 | 6.0 |
| Sounds by other animals (dogs, cats, foxes, birds) | 0.4 | 1.6 | 7.6 | 11 | 79.1 | 32.6 |
| Other sounds (people in the house, on the street, bed partner) | 1.2 | 1.8 | 7 | 8 | 81.5 | 32.2 |

### Does noise annoyance relate to the objectively measured noise exposure?

The ranking of the daytime noise sources is listed in Table 2 for daytime on workdays at home, in Table 3 for daytime on weekends at home and in Table 4 for the work-place. The score was calculated similarly as for the nighttime noise sources.

**Table 2:** Answers (in %) to the question 'how much are you annoyed or incommoded by the following sound sources during the day on work days at home?'

| | Very much | Much | Middle | A little | Not at all | Score |
|---|---|---|---|---|---|---|
| Road traffic | 3.2 | 3.2 | 10.6 | 23 | 59.7 | 66.6 |
| Machines and equipment | 2.8 | 3.3 | 9.8 | 21 | 62.7 | 61.7 |
| Neighbors | 2.3 | 2.0 | 7.6 | 18.9 | 68.9 | 49.3 |
| Aircraft | 2.4 | 1.9 | 6.4 | 15.6 | 73.4 | 43.7 |
| Animals | 2 | 1.4 | 4.5 | 13.9 | 78 | 35.1 |
| Church bells | 2.8 | 1.3 | 4.1 | 10.7 | 80.8 | 34 |
| Rail | 2.5 | 1 | 4.9 | 8.3 | 82.9 | 31.1 |
| Restaurants, music, events | 2.5 | 1.3 | 3.4 | 8.6 | 83.9 | 29.3 |
| Other sounds | 0.6 | 1.4 | 3.8 | 6.1 | 87.5 | 20.3 |
| Industry | 2.5 | 0.7 | 1.8 | 4.2 | 90.5 | 19.9 |

**Table 3:** Answers (in %) to the question 'how much are you annoyed or incommoded by the following sound sources during the day on weekends at home?'

| | Very much | Much | Middle | A little | Not at all | Score |
|---|---|---|---|---|---|---|
| Road traffic | 2.1 | 2.4 | 8.4 | 19.8 | 67 | 52.2 |
| Neighbors | 1.5 | 1.8 | 6.2 | 16.2 | 73.9 | 40 |
| Aircraft | 1.7 | 1.5 | 4.8 | 13.2 | 78.4 | 34.1 |
| Machines and equipment | 1.5 | 1.3 | 4.9 | 12.3 | 79.7 | 32 |
| Church bells | 1.7 | 1 | 3.7 | 9.3 | 83.9 | 26.5 |
| Animals | 1.3 | 0.9 | 3.3 | 11.5 | 82.6 | 26 |
| Rail | 1.4 | 0.8 | 3.4 | 8.1 | 86 | 22.9 |
| Restaurants, music, events | 1.3 | 0.9 | 3.1 | 7.5 | 86.8 | 21.6 |
| Industry | 1.3 | 0.5 | 1 | 2.2 | 94.8 | 10.9 |
| Other sounds | 0.8 | 0.9 | 1.6 | 4.7 | 91.5 | 13.8 |

**Table 4a**: Answers (in %) to the question 'how much are you annoyed or incommoded by… ?' (only employed people asked, 58.4 % of interviewees)

| | Very much | Much | Middle | A little | Not at all | Score |
|---|---|---|---|---|---|---|
| Sounds produced at the working place | 2.7 | 6.6 | 17.5 | 21.2 | 51.4 | 86.8 |
| Non company related sounds | 1.7 | 2.3 | 7.9 | 11.2 | 76.2 | 40.7 |

**Table 4b**: Answers (in %) to the question 'by which non company related sounds?'

| | |
|---|---|
| Road traffic | 42.8 |
| Construction noise | 22.4 |
| Humans | 10.5 |
| Aircraft | 9.0 |
| Railway | 8.3 |

**Table 5:** Spearman's Rank correlation between subjectively rated noise annoyance and objectively modeled noise in the environment a person lives; all values were statistically significant with $p<0.001$

| Noise source and time | Road day | Road night | Plane day | Plane night | Train day | Train night |
|---|---|---|---|---|---|---|
| Correlation Coefficient | 0.12 | 0.12 | 0.12 | 0.10 | 0.22 | 0.23 |

### Does sensitivity to noise relate to objectively modeled noise exposure and subjective quality?

There were no significant correlations between subjective sensitivity to noise and objectively modeled noise exposure (all r values <0.05, all p values > 0.2). However, people with high scores on the noise sensitivity questionnaire also rated their sleep quality worse. Thus, correlation analyses, yielded significant negative correlation between sensitivity to noise and sleep quality (r=-0.23, p<0.0001).

## DISCUSSION

### Sleep times in Swiss residents?

Our survey yielded clear work- versus free days as well as age-dependent effects on sleep times in Swiss residents. These effects were most pronounced in the wake up times, which encompassed a broad time range from 04:00 to 13:00. Wake up times differed considerably between work - and free days, particularly for young residents (< 30 years). In contrast, sleep times differed to a lesser extent than wake-up times between work - and free days. The difference in sleep phase preference between workdays and weekends corroborates earlier findings in the literature (Borbély 1984; Roenneberg et al. 2003; Groeger et al. 2004; Frey et al. 2009; NSL 2010) and gives evidence to a sleep debt, which accumulates during the working week (Taillard et al. 1999). This phenomenon has also been referred to as a “social jet lag”, since societal working demands during the week hinders biological demands for sleep (Roenneberg et al. 2003). The observed averaged sleep duration of 7.5 hours on work days in our Swiss resident sample was about 30 minutes longer when compared to a similar survey in a representative sample of some 2,000 British residents (Groeger et al. 2004).

Since, in our survey Swiss residents < 12 years were not interviewed, we included information on bed- and wake time from the Zurich longitudinal studies. However, in this survey sleep times were not given separately for workdays and weekends. Thus, table 6 just shows bed- and wake times from infancy to teen age (up to <14 years).

**Table 6**: Bedtime and wake time (3rd cohort, in hours:minutes with SD) of infants to adolescents (from Table 2 in Iglowstein et al. (2003)).

| | **6 Months** | **1 Year** | **3 Years** | **5 Years** | **10 Years** | **14 years** |
|---|---|---|---|---|---|---|
| Bedtime | 20:16 (1:08) | 19:46 (0:50) | 20:07 (0:42) | 20:11 (0:38) | 20:59 (0:40) | 22:02 (0:37) |
| Wake time | 7:13 (0:13) | 7:19 (0:52) | 7:35 (0:50) | 7:20 (0:39) | 6:56 (0:29) | 6:30 (0:20) |

The proportion of children in the Swiss Population (2008-2009 FSO) is of around 6 % for the 0 to 5 years old, of 5 % for the 6 to 10 years old and of 4 % for the 11 to 14 years old. The 12 to 19 years old account for approximately 9 % of the population.

Taking the data of our and of the Zurich survey, we calculated that around 9 % of the population is asleep at 21:00 on work days and weekends, whereas at 22:00, 20 % of the population is asleep on workdays and 16 % on free days. At 06:00 in the morning, 78 % of the population is still asleep on workdays and even more (95 %) on free days, while at 07:00 this proportion falls to 35 % on workdays and 81 % on free days. On free days, 25 % of the population aged 12 and more were still asleep at 09:00. The median wake up time for 12 to 19 years old residents was 10:00 and the upper quartile 11:00 for the 12 to 15 years old and 12:00 for the 16 to 19 years old respectively.

Based on our survey, we have evidence that a nightly protection from noise between 22:00 and 06:00 may not be sufficient. This is particularly true for the morning value (i.e. 6:00) with 78 % of the population still asleep on workdays and 95 % on free days. Thus, noise protection only until six o' clock in the morning may not be appropriate for a large part of the population. Since the timing of sleep is driven by an intrinsic biological clock, it is difficult to force people to sleep during the most quiet time of the night (i.e. midnight to 6 am), which would only comprise 6 hours of sleep. According to our survey, 90 % of the Swiss residents sleep more than 6 hours on work days and almost all (95 %) on weekends. Thus, according to our results, a time window of 9 hours for sleep ideally placed between 22:00 and 7:30 accommodates 90 % of the Swiss population on work days, while these time points considerably shift on free days for 90 % of the population as follows: 10 hours of sleep ideally placed between 22:30 and 10:00. Although these times are optimal for 90 % of the population, the late chronotypes (about 5 to 10 % of the population) who suffer most of the misalignment of biological and social time leading to shortened sleep (Wittman et al. 2006) would still not fit in the proposed time window for sleep in order to get enough sleep. Thus, it was no coincidence that adolescents and young adults in our survey showed the latest wake-up times on weekends. Indeed, there is a shift of the sleep phase preference during the adolescence (Carskadon et al. 1997, 2004; Frey et al. 2009).

The consequences of poor or too little sleep are daytime fatigue, drowsiness and sleepiness, which lead to impaired attention and learning. This can lead to accidents, injuries and deaths due to lapses in attention and delays in reactions for instance while driving. In the US, young drivers under the age of 25 are involved in more than half of the fall-asleep crashes (National Sleep Foundation 2010; Adolescent Sleep Needs and Patterns). On the longer term, poor sleep and sleep curtailment has effects on performance and health such as cardiovascular and metabolic diseases (Carskadon & Dement 1981; Curcio et al. 2006; Meerlo et al. 2008; Spiegel et al. 2009; van Cauter et al. 2007, 2008; van Dongen et al. 2003).

It has been repeatedly shown that noise has a negative impact on sleep (Muzet 2007). Even young healthy good sleepers can be awakened by noise of only 40 dBA (Dang-Vu et al. 2010). The current noise impact thresholds in Switzerland for sensitivity zone II are of 60 dBA for daytime and 50 dBA for night time, calculated based on yearly mean levels. Thus, for short periods much higher levels are possible.

**Which are the noise sources responsible for noise-related sleep disturbances?**

The results of the noise sources disturbing sleep suggest that noise from the family, pets and neighbors are as disturbing as road traffic noise, which all comprise the top three hits according to Table 1. Besides these top three noise sources, other important sources, in terms of number of people disturbed by noise at night, was noise from restaurants, music and events as well as church bells, which were more disturbing than noise from aircrafts and trains in Switzerland.

**Does noise annoyance relate to the objective noise exposure?**

In Tables 2 to 4, the sources of daytime noise disturbances are listed in ranked order. As for the night, road traffic was on the first place on workdays and on weekends.

This is in accordance with the rank order in number of people exposed above threshold levels as calculated in sonBase. Although, there are much more people exposed to railway noise above threshold levels than to aircraft noise, there were more people being annoyed or disturbed by aircraft noise both on workdays and on weekends. However, most people were disturbed by neighborhood noise and on workdays also by machines and equipment. The correlation between subjective noise assessment and objective noise exposure was statistically significant for all available variables but with relatively low r-values. However, this indicates that objectively modeled noise exposure can be used as a proxy for subjective noise annoyance in a specific region.

### Does sensitivity to noise relate to subjective sleep quality and objectively modeled noise exposure?

Noise sensitivity as assessed with a short questionnaire did not correlate with modeled noise exposure. This either indicates that noise sensitive people avoid “noisy” places for living, or that noise sensitivity is not influenced by the noise levels of the environment. However, as intuitively assumed, noise sensitive people also reported impaired sleep quality, as indexed by a negative correlation between noise sensitivity and sleep quality.

In summary, our survey data give evidence that the critical nighttime period for noise protection should ideally comprise 9.5 hours from 22:00 to 07:30 on workdays and 11.5 hours from 22:30 to 10:00 on free days. With appropriate noise protection this time window could ideally allow undisturbed sleep for 90 % of the Swiss population. Besides noise of the closest vicinity by family members, pets and neighbors, road traffic noise is the most common complaint of Swiss people affecting their sleep and did significantly correlate with modeled noise data.

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# Impact of nocturnal railway and aircraft noise on awakening probability in the field

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ABSTRACT

**Objectives**. Surveys suggest that railway noise is less annoying than aircraft noise. A study on air, road and rail traffic noise conducted by the DLR-Institute of Aerospace Medicine showed that this order is inversed regarding awakening reactions during sleep in the laboratory. The present study investigated event-related awakening reactions during sleep in a field study on railway noise comparing the results with a similar study on aircraft noise.

**Methods**. 33 healthy participants (mean age 36.2 years ± 10.3 (SD); 22 females) living alongside railway tracks around Cologne/Bonn (Germany) were polysomnographically investigated during nine consecutive nights. The probability of noise-induced awakenings was analysed basing on 8,866 recorded noise events. In a second step, these data were compared with data from a field study on aircraft noise including 64 subjects and 10,658 noise events directly comparing the effects of railway and aircraft noise in one model.

**Results**. Probability of sleep stage changes to wake/S1 from railway noise increased significantly from 5.2 % at 30 dBA to 15.0 % at 70 dBA $L_{AFmax}$. Comparing railway noise and aircraft noise, awakening probability decreased in the order freight train noise, aircraft noise, passenger train noise.

**Conclusions**. Nocturnal freight train noise leads to significantly increased awakening probabilities which are higher than for aircraft noise, supporting the order found in the laboratory and contrasting the findings of annoyance surveys. Sound pressure rise time of the noise event proved to be one important factor for explaining different reaction probabilities during sleep.

# Adverse health effects of industrial wind turbines: a preliminary report

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## INTRODUCTION

Guidelines and regulations for the siting of industrial wind turbines (IWT) close to human habitation are generally predicated on the need to protect the sleep of the residents. The recommended setback distances and “safe” external noise levels make the assumptions that IWT noise can be regarded as similar to other forms of environmental noise (traffic, rail and aircraft) and is masked by ambient noise. There has been no independent verification that these assumptions are justified and that the safeguards are sufficient to protect sleep.

Anecdotal complaints of annoyance and health effects from IWT noise have grown in number in recent years, not least because turbine size has increased and they have been placed closer to population centers. The predominant symptom of health complaints is sleep disturbance (Frey & Hadden 2007; Pierpont 2009; van den Berg et al. 2008; WindVOICe 2010). The consequences of sleep disturbance and the contribution of environmental noise are well documented (WHO 2009).

Complaints of adverse health effects were made shortly after IWT installations at Mars Hill and Vinalhaven, Maine, USA, began operating. A preliminary survey at Mars Hill, comparing those living within 1,400 m with a control group living 3,000-6,000 m away showed that sleep disturbance was the main health effect (Nissenbaum 2011, submitted for publication). A further study was therefore carried out at both Mars Hill and Vinalhaven using validated questionnaires and comparing those living within 1.5 km of the turbines with a control group living 3,500-6,000 m away.

## METHODS

### General study design

A questionnaire was offered to all residents meeting inclusion criteria living within 1.5 km of an IWT and to a random sample of residents meeting inclusion criteria living 3 to 7 km from an IWT between March and July of 2010. The protocol was reviewed and approved by IRB Services, Aurora, Ontario, Canada.

### Questionnaire

The questionnaire comprised validated instruments relating to mental and physical health (SF-36v2) (QualityMetric Inc.), sleep disturbance (Pittsburgh Sleep Quality Index (PSQI) (Buysse et al. 1989) and the Epworth Sleepiness Scale (ESS) (Johns 1991), in addition to headache functional inquiry questions and a series of attitudinal questions relating specifically to changes with exposure to IWT noise. Only the results from the validated instruments are presented here.

## Participant selection

The Mars Hill site is a linear arrangement of 28 General Electric 1.5 megawatt turbines, sited on a ridgeline. The Vinalhaven site is a cluster of three similar turbines, sited on a flat tree covered island. All residents living within 1.5 km of an IWT at each site were identified via tax maps, and approached either door to door or via telephone and asked to participate in the study. Homes were visited up to three times or until contact was made. Those below the age of 18 or with a diagnosed cognitive disorder were excluded. A random sample of households in a similar socioeconomic area 3 to 7 km away from IWTs at each site was chosen to participate in the study as a control group. Households were approached door-to-door until a similar number of participants were enrolled.

## Data handling and validation

Questionnaire results were coded and entered into a spreadsheet (Microsoft Excel 2007). The distance from each participant's residence to the nearest IWT was measured using satellite maps. SF36-V2 responses were processed using QualityMetric Health Outcomes™ Scoring Software 3.0 to generate Mental (MCS) and Physical (PCS) Component Scores. Missing values were verified and outliers were individually assessed. Data quality of the SF36-V2 responses was determined using QualityMetric Health Outcomes™ Scoring Software 3.0. All SF36-V2 data quality indicators (completeness, response range, consistency, estimable scale scores, internal consistency, discriminant validity, and reliable scales) exceeded parameter norms.

## Statistical analysis

All analyses were performed using SAS 9.22. Descriptive and multivariate analyses were performed to investigate the effect of the main independent variable of interest (distance to nearest IWT) on the various outcome measures.

Significance of binomial outcomes was assessed using either the GENMOD procedure with binomial distribution and logit link; or when cell frequencies were small (<5), Fisher's Exact Test. When assessing significance between variables with a simple score as the outcome (eg. 1-5), the exact Wilcoxson Score (Rank Sums) test was employed using the NPAR1WAY procedure. Significance of continuous outcome variables was assessed using the GENMOD procedure with normal distribution. When using the GENMOD procedure, age, gender and site were forced into the model as fixed effects. The potential effect of household clustering on statistical significance was accommodated by using the REPEATED statement.

Independent variables assessed included the following: Site (Mars Hill, Vinalhaven); Distance to IWT (both as a categorical and continuous variable); Age (continuous variable); Gender (categorical variable). Significance of Site as an effect modifier was assessed by fitting an interaction term (Site*distance).

Dependent variables assessed include the following: Epworth Sleepiness Scale (ESS), Pittsburgh Sleep Quality Index (PSQI), SF36-v2 Mental Component Score (MCS), SF36-v2 Physical Component Score (PCS).

For the purpose of interpreting statistical significance, the following were used: P-value < 0.05 = Significant; P-value 0.1 – 0.05 = Moderately significant; P-value > 0.1 = Not significant.

### Effect of Site on outcome parameters

The effect of Site was assessed by fitting Site (Mars Hill vs Vinalhaven) as a fixed effect, and as an interaction term with the main independent variable of interest (distance). Among all outcomes investigated, Site, and Site*Distance were not significant.

## RESULTS

### Study participants

33 and 32 adults were identified as living within 1,500 m of the nearest IWT at the Mars Hill (mean. 805 m, range 390-1,400) and Vinalhaven sites (mean 771 m range 375-1,000) respectively. 23 and 15 adults at the Mars Hill and Vinalhaven sites respectively completed questionnaires. Recruitment of control group participants continued to approximately the same number as study group participants, 25 and 16 for Mars Hill and Vinalhaven respectively.

There were no significant differences between the groups with respect to household size, age, or gender (Table 1).

**Table 1:** Demographic data

| | Distance range from residence to nearest IWT (mean) in meters | | | |
|---|---|---|---|---|
| Parameter | 375-750 (601) | 751-1,400 (964) | 3,300-5,000 (4,181) | 5,300-6,600(5,800) |
| Sample size | 18 | 20 | 14 | 27 |
| Household clusters | 11 | 12 | 10 | 23 |
| Mean age | 50 | 57 | 65 | 58 |
| Male/Female | 10/8 | 12/8 | 7/7 | 11/16 |

### Sleep quality and health

The study group had worse sleep as evidenced by significantly higher mean PSQI and ESS scores and a greater number with PSQI >5 (Table 2). More subjects in the study group had ESS scores >10 but the difference did not reach statistical significance (p=0.1313).

The study group had worse mental health as evidenced by significantly higher mean mental component score of the SF36. There was no difference in the physical component scores.

**Table 2:** Sleep and mental health parameters

| Parameter | Distance to IWT: Range (mean) m | | p |
|---|---|---|---|
| | 375-1,400 (792) | 3,000-6,600 (5,248) | |
| PSQI Mean (LSmean) | 7.8 (7.6) | 6.0 (5.9) | 0.0461 |
| % PSQI >5 | 65.8 | 43.9 | 0.0745 |
| ESS Mean (LSmean) | 7.8 (7.9) | 5.7 (5.7) | 0.0322 |
| % ESS >10 | 23.7 | 9.8 | 0.1313 |
| SF36 MCS Mean (LSmean) | 42.0 (42.1) | 52.9 (52.6) | 0.0021 |

ESS, PSQI and SF36 scores were modeled against distance from the nearest IWT using the equation: Score = ln(distance) + gender + age + site [controlled for household clustering] and are shown in Figures 1-3. In all cases, there was a clear and significant relationship with the effect diminishing with increasing distance from the IWT.

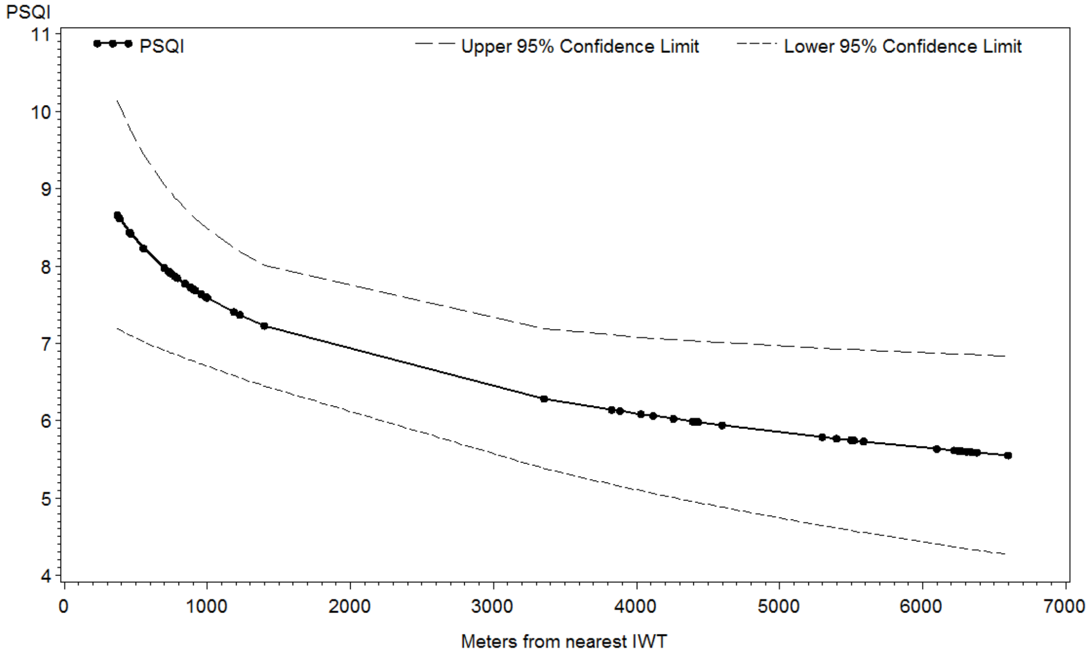


**Figure 1:** Modeled Pittsburgh Sleep Quality Index (PSQI) vs Distance
(mean and 95 % confidence limits), p-value=0.0198

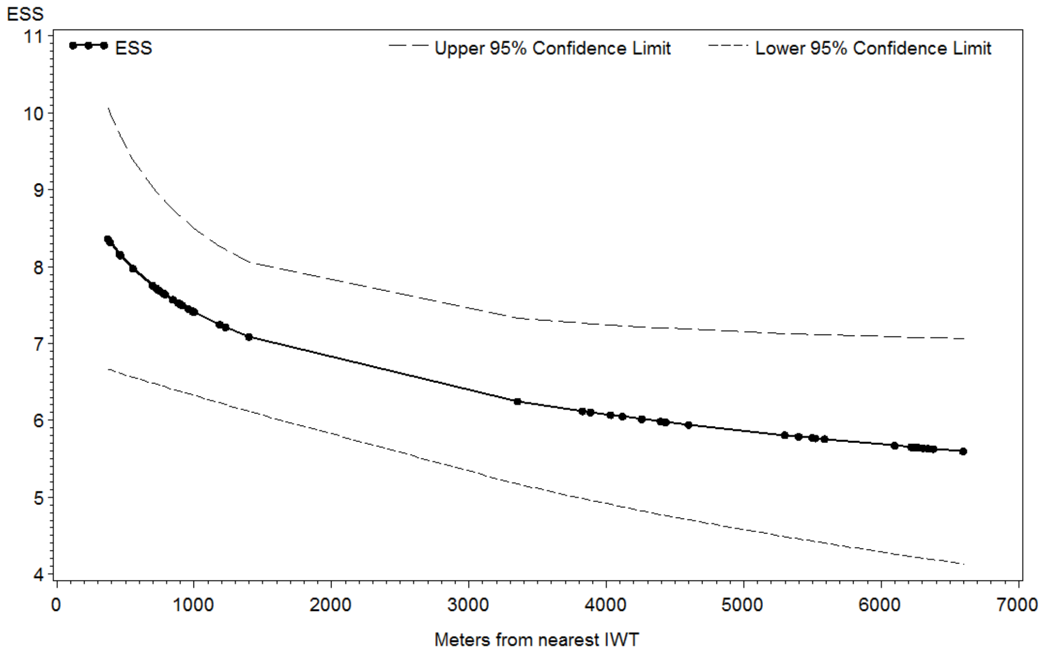


**Figure 2:** Modeled Epworth Sleepiness Scale (ESS) vs Distance
(mean and 95 % confidence limits), p-value=0.0331

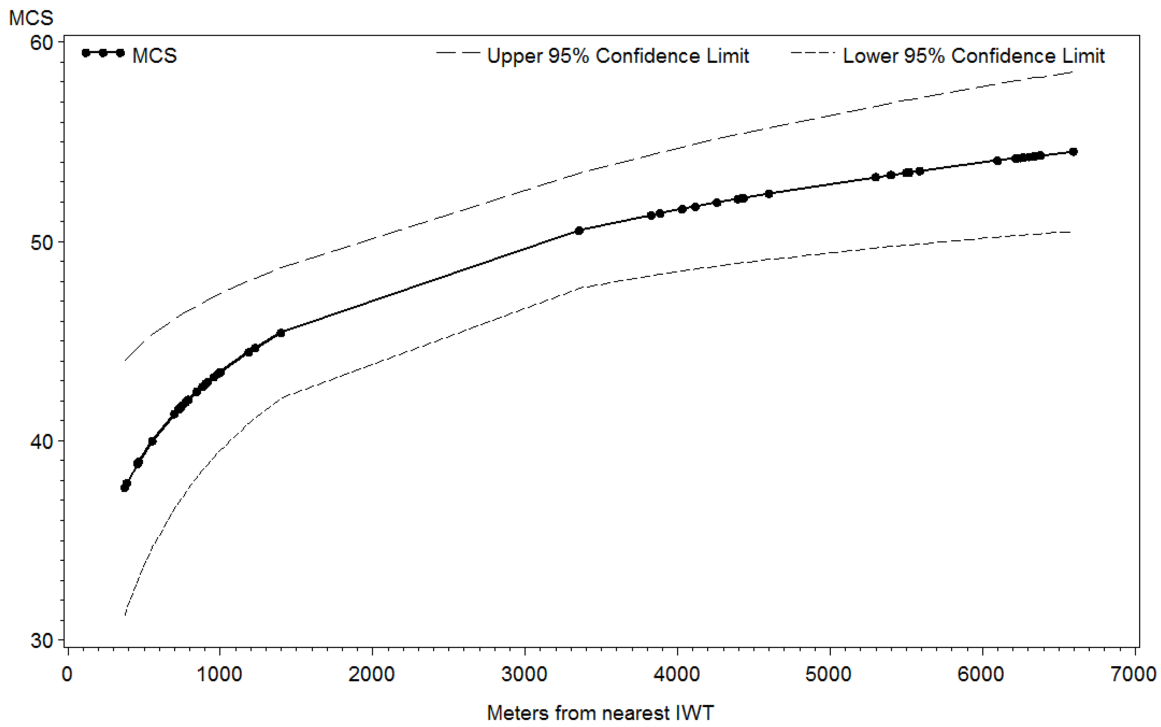


**Figure 3:** Modeled SF36 Mental Component Score (MCS) vs Distance (mean and 95 % confidence limits), p-value=0.0014

## DISCUSSION

This study, which is the first controlled study of the effects of IWT noise on sleep and health, shows that those living within 1.4 km of IWT have suffered sleep disruption which is sufficiently severe as to affect their daytime functioning and mental health. Both the ESS and PSQI are averaged measures, i.e. they ask the subject to assess their daytime sleepiness and sleep quality respectively, over a period of several weeks leading up to the present. For the ESS to increase, sleep must have been shortened or fragmented to a sufficient degree on sufficient nights for normal compensatory mechanisms to have been overcome. The effects of sleep loss and daytime sleepiness on cognitive function, accident rate and mental health are well established (WHO 2009) and it must be concluded that at least some of the residents living near the Vinalhaven and Mars Hill IWT installations have suffered serious harm to their sleep and health.

The significant relationship between the symptoms and distance from the IWTs, the subjects' report that their symptoms followed the start of IWT operations, the congruence of the symptoms reported here with previous research and reports and the clear mechanism is strong evidence that IWT noise is the cause of the observed effects.

IWT noise has an impulsive character and is several times more annoying than other sources of noise for the same sound pressure level (Pedersen & Persson Waye 2004). It can prevent the onset of sleep and the return to sleep after a spontaneous or induced awakening. Road, rail and aircraft noise causes arousals, brief lightening of sleep which are not recalled. While not proven, it is highly likely that IWT noise will cause arousals which may prove to be the major mechanism for sleep disruption. It is possible that the low frequency and infrasound components of IWT noise might contribute to the sleep disruption and health effects by other mechanisms but this remains to be determined and further research is needed.

Attitudes to IWT and visual impact have been shown to be factors in annoyance to IWT noise (Pedersen et al. 2009) but have not been demonstrated for sleep disturbance. Most respondents in the present study welcomed the IWT installations as offering economic benefits. The visual impact of IWT decreases with distance, as does the noise impact making separation of these factors impossible.

We conclude that IWT noise at these two sites disrupts the sleep and adversely affects the health of those living nearby. The current ordinances determining setback are inadequate to protect the residents and setbacks of less than 1.5 km must be regarded as unsafe. Further research is needed to determine a safe setback distance and to investigate the mechanisms of causation.

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# A critical review of current policy for the assessment of night-time noise in the EU

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## ABSTRACT

This paper explores issues surrounding the estimation of population exposure data in accordance with EU Directive 2002/49/EC (European Commission 2011) and, in particular, focuses on the assessment of night-time noise. It has been identified by many authors that no standardised method for estimating population exposure to noise exists. Thus, results from noise exposure studies across Member States cannot be compared reliably or combined. For sleep disturbance assessments, the issue is further compounded by the use of methodologies that are not fully understood. Significant concern exists over the use of the new $L_{night}$ indicator, which is measured over eight hours, as sleep disturbance studies to date rarely cover this period and noise indices do not usually include $L_{night}$. Furthermore, assessments are performed using calculations at the position of the most exposed façade, while the impact of using this position, with respect to the bedroom, has not been fully quantified. This paper summarises the practical issues associated with the assessment of night-time noise in accordance with the requirements of EU Directive 2002/49/EC. Possible solutions are suggested including further guidance and the creation of an EU data infrastructure that would significantly improve benchmarking and comparison of future exposure studies under the terms of the Directive.

## INTRODUCTION

The EU issued Directive 2002/49/EC, the Environmental Noise Directive, to establish a framework for environmental noise planning. This Directive called for the production of environmental noise maps for designated areas as well as the development of appropriate noise action plans and noise mitigation measures. Largely in response to the Directive extensive noise studies have been undertaken for the first time in many Member States. The first phase of these noise mapping studies has been completed and results have been published online by the European Environment Agency (EEA) via the "*Noise Observation and Information Service for Europe (NOISE*)"[1].

Member States were required to develop strategic noise maps by June 30th 2007, for all agglomerations[2] of over 250,000 inhabitants, all major roads with over 6 million passages a year, major railways with more the 60,000 train passages a year and major airports with over 50,000 take-off or landing movements a year. A second phase of maps, due in 2012, will also require maps to be made of agglomerations of over 100,000 inhabitants, roads with over 3 million vehicle passages a year and railways with over 30,000 train passages a year. The Directive defined two specific indicators that must be used when presenting strategic noise maps: $L_{den}$ and $L_{night}$. $L_{den}$, the

[1] http://noise.eionet.europa.eu

[2] 'agglomeration' shall mean part of a territory, delimited by the Member State, having a population in excess of 100 000 persons and a population density such that the Member State considers it to be an urbanized area (Article 3, EU Directive 2002/49/EC)

day-evening-night noise indicator, represents the noise indicator for overall annoyance expressed in dBA while $L_{night}$ acts as the noise indicator for sleep disturbance

A number of methodological issues concerning the implementation of the Directive have been identified and discussed by academics (Murphy & King 2010) and the European Commission also contracted a project to review the experiences of Member States in implementing the Directive (Milieu Ltd. 2010). These reports highlight a number of issues associated with the implementation of the Directive that should be considered in any review and amendment of the legislation. For example Murphy & King (2010) identified that there is no standardized method for estimating population exposure to noise; thus, results from noise studies across Member States cannot be reliably compared at present. This was also recognized in the Milieu report which noted that a number of Member States have called for a common methodology with which to measure exposed populations. Another area of concern is the use of the most exposed façade in results. For strategic noise maps, assessment points are placed at the most exposed façade (the external wall facing onto and nearest to the specific noise source) and the $L_{den}$ and $L_{night}$ levels are calculated at these points. $L_{night}$ is then used to assess sleep disturbance but sleep disturbance studies to date have not used this new indicator or the façade position (WHO 2009).

This paper focuses on the issue of night-time noise area and summarizes the practical issues associated with the current policy for the assessment of night-time noise in the EU.

## Noise and health

The relationship between environmental noise and public health is perhaps the most significant reason why environmental noise has emerged as a major issue in environmental legislation and policy in recent years (Berglund et al. 1999). Much research has emerged over the last two decades linking environmental noise with adverse health effects. Recently the World Health Organisation (WHO) estimated that at least 1 million healthy life years are lost every year from traffic-related noise in the western European countries, including the EU Member States (WHO 2011). In terms of strategic noise mapping, annoyance and sleep disturbance are considered to be the two most prominent adverse effects of prolonged exposure.

Annoyance is the scientific expression for the non-specific disturbance by noise, as reported in a structured field survey (European Commission 2000). Evidence of annoyance includes, for example, the reduced enjoyment of use of a garden or closing windows in order to avoid sleep disturbance. Studies have shown that noise annoyance from transportation produces a variety of negative emotions including anger, disappointment, unhappiness, anxiety and even depression (Fields 1998; Miedema 2003; Michaud et al. 2005). Many different factors will affect the extent of annoyance on any individual, for example, intermittent noise is more annoying than continuous noise and narrow band signals are generally more annoying than wider band signals. In addition it has been found that long-term annoyance is slightly, but statistically significantly, higher in the summer than in the winter (Miedema et al. 2005) while marital status and gender may significantly affect the annoyance level caused by traffic noise (Abo-Qudais & Abu-Qdais 2005).

Exposure to environmental noise may also affect people's ability to gain the appropriate amount of sleep required for the maintenance of good health. Sleep disturbance is seen as a health effect on its own, but may also cause after effects such as mood changes, fatigue and other impaired functions. Research conducted by Ohrstrom & Skanberg (2004) has shown that sleep quality at home is reduced after exposure to traffic noise when compared to a quiet reference night while Carter (1996) has shown that exposure to noise during the night can lead to considerable disruption in the stages of the sleep cycle. Exposure to night-time noise can also produce a number of secondary effects (i.e. those that can be measured the day after the individual is exposed to night-time noise). The WHO LARES report notes that particular attention should be paid to night-time noise exposure as more people are affected by noise induced sleep disturbance than noise induced strong annoyance.

A further area of concern is the link between noise exposure and cardio-vascular disease (Babisch et al. 2003). The Hypertension and Exposure to Noise Near Airports (HYENA) Study found that night time noise exposure and road traffic noise were associated with increased risk of hypertension. Another worrying aspect of exposure to environmental noise includes the effect it may have on the cognitive development of children. The Road traffic and Aircraft Noise exposure and children's Cognition and Health (RANCH) Study found that chronic aircraft noise exposure affects reading comprehension and recognition memory.

**Methodological issues associated with assessing night-time noise**

The WHO recently released "Night Noise Guidelines for Europe" which reviewed scientific evidence on the health effects of night noise and derived health-based guideline values for noise (WHO 2009). The document notes that $L_{night}$ is a relatively new noise indicator and, as such, sleep disturbance studies to date rarely cover the 8-hour night-time period and data are seldom expressed in terms of $L_{night}$. Additionally, surprisingly little information is available on the exposure of houses to night-time noise. The document also notes that further research is needed to gain an insight into the contribution of various noise sources to sleep disturbance. Furthermore, the Milieu Report notes that a major limitation of the current EU exposure-response relationships is that they do not take account the difference in exposure between the most exposed façade and the bedroom façade, as well as the difference between the outdoor exposure at the bedroom façade and the indoor exposure within the bedroom (Milieu Ltd. 2010). The report also notes that more research should be directed to a potential improvement of the prediction of subjective sleep disturbance by adding noise descriptors other than $L_{night}$, such as noise in the early or late parts of the night, descriptors of peak levels, or number of events.

In epidemiological studies, self-reported sleep disturbance is the most easily measurable outcome indicator, because electro-physical measurements are costly and difficult to carry out on large samples and may themselves influence sleep (WHO 2011). To date, research on noise and associated sleep disturbance has been broad and covered many different domains and disciplines. Tests have been conducted both in the field and in laboratory environments. In these tests, noise is often played over loudspeakers or headphones and the quality of the subjects' sleep is usually assessed by actigraphs or questionnaires. However, in most tests the noise indicators are assessed with respect to the subject's sleep quality and are not in terms of the new $L_{night}$ indicator, while the noise level of interest is, logically, the indoor noise level, whereas strategic noise maps report the outdoor façade level. One exception may be the study conducted by Graham et al. (2009) who recorded both internal and external noise during the night period, but in this case, the external monitoring position was in the vicinity of the road and not at the most exposed façade. It has been noted that recording indoor noise levels in the bedroom of each test would provide the most exact and reliable noise values, however, this process is time consuming and cumbersome (Pirrera et al. 2010).

There is also an issue with the extent of mapping required with research showing that the thresholds for noise mapping defined in the Directive may lead to a large underestimation of noise annoyance. Borst & Miedema (2005) suggest that the $L_{den}$ limit of 55 dB should be lowered while a recent Commission report cites the WHO recommendation of lowering the $L_{night}$ limit to 40 dB. It is questionable if today's noise calculation methods can accurately predict noise to these low levels, thus the need for a new improved method, validated at low noise levels, has emerged.

While significant work has been conducted in the area of night-time noise there still remain significant gaps in the assessment process, particularly when relating results contained in strategic noise mapping studies to actual night-time impacts. The results of the strategic noise mapping were mostly (only) graphical noise maps and community specific statistical data showing the estimated number of people within dB classes (Petz 2008). Information on the number of dwellings, hospitals and schools affected by noise levels summarized in 10 dB classes were also available. The usefulness of this data for action planning has been questioned (Petz 2008). For night-time noise assessments much more detail is required. It seems the current level of detail will not be enough to develop appropriate and consistent action plans to address night-time noise. Furthermore, the role of specific night-time noise mitigation measures is a particular area in which further detailed research is required.

With regard to action planning it has been noted that the information reported to the Commission was very diverse and the data were scattered, consequently, a comprehensive analysis of the action plans proved challenging and is still ongoing (European Commission 2011). The Eurocities Position paper[3] on the END notes that, despite the successful implementation of the END and the availability of noise maps and action plans, until then (May 2009) there was little evidence to suggest that any significant progress in avoiding, preventing and reducing environmental noise was made. The same must be true for night-time noise. It is clear that the problem is not yet fully understood and further research is needed both in the assessment and the design of mitigation measures for night-time noise.

## POTENTIAL FOR IMPROVEMENT

### Guidance documents

A number of guidance documents have been developed and outline approaches to the development of noise action plans. Increased guidance should improve consistency across different studies. Often guidelines are National guidance documents or as a result of European Framework projects (e.g. Silence, Qcity). In the case of sleep disturbance the Qcity project recommend the use of a measure describing the percentage of people who are highly sleep disturbed (%HSD). It is a similar measure to %HA (percentage highly annoyed) which has been widely used in the past. However this method has also been subject to criticism. Probst (2006) notes that the

[3] http://workinggroupnoise.web-log.nl/mijn_weblog/2009/07/position-paper.html

%HA concept provides a very weak weighting of levels and the results will in many cases not reflect people's opinion about a fair distribution of unavoidable hazards.

**CNOSSOS-EU – Technical Group of Experts**

In line with EU Directive 2002/49/EC, the European Commission decided to prepare Common Noise Assessment Methods across the EU (CNOSSOS-EU), for the purposes of strategic noise mapping, in order to improve the reliability and comparability of noise mapping results. During the Regulatory Committee on Noise (June 2010), EU Member States were invited to nominate experts to be involved in the next steps of the process related to the development and implementation of CNOSSOS-EU. The first meeting of this expert group took place in November 2010. This expert group recently established a number of working groups to assess various aspects of a common calculation method addressing the requirements of the Directive. It is hoped that these groups will consider the issue of night-time noise in detail and will suggest a more appropriate methodology for the assessment of night-time noise exposure.

**Developing an EU data infrastructure**

King and Rice (2009) noted that to truly achieve complete standardization in noise mapping studies, competent authorities would be required to use both the same calculation method and software format. They suggest that this could be achieved at a European level by establishing a repository making (ideally open source) software available to those authorities that may wish to avail of it. In parallel with this the creation of an EU data infrastructure could be utilized to achieve an appropriate level of consistency across different noise studies including population exposure assessments and night-noise assessments. This would significantly improve benchmarking and comparison of future exposure studies under the terms of the Directive.

## DISCUSSION

Environmental noise is a serious environmental concern. It will also affect future generations and has socio-cultural, aesthetic and economic repercussions (Bjorner 2004). According to the World Health Organization, the growth in urban environmental noise pollution is unsustainable, because it involves both the direct and cumulative adverse effects on health and also adversely affects future generations by degrading residential, social and learning environments (Berglund et al. 1999). Indeed reducing transport noise both at source and through mitigation measures to ensure overall exposure levels minimize impacts on health is an objective of the EU Sustainable Development Strategy. Unfortunately, environmental noise has received little attention in the past with Dr. Rokho Kim of the WHO Regional Office for Europe recently stating "while almost everyone is exposed to too much noise, it has traditionally been dismissed as an inevitable fact of urban life and has not been targeted and controlled as much as other risks"[4].

While significant advancements have been made in Europe over the last few years there still remains the need for further research in the area of environmental noise, with particular need for improved knowledge on night-time noise. Estimates of population exposure resulting from strategic noise mapping studies are currently incompa-

[4] WHO Press Release, October 2009, "*One in five Europeans is regularly exposed to sound levels at night that could significantly damage health*".

rable due to the significant differences in estimation methodology. Additional concern exists over the use of façade levels to determine sleep disturbance while the WHO have identified that further research is needed regarding the use of the $L_{night}$ indicator to assess sleep disturbance. The WHO Night Noise Guidelines also recognize that there is a need to conduct further research to analyze the contribution of various noises to sleep disturbance while the authors believe the role of night time noise mitigation measures has not yet been adequately developed.

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# Sleep disturbing effects of nightly church bell ringings and aircraft noise in the Swiss population - an impact analysis

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ABSTRACT

Most research on noise and sleep disturbance considers transportation noise sources (road traffic, railways, and aircraft) and very little knowledge exists about the sleep disturbing effects of nocturnal ambient noise sources such as noises from neighbors, from people on the street, from restaurants and bars, or sounds from church bells. In a field study, we investigated the exposure-awakening effect of different ambient noises, with special focus on church bell noise. Results indicate that the bell ringing events increase awakenings in a similar fashion as has previously been reported with transportation noise events. Based on the derived awakening probability functions and on population number estimates in the vicinity of churches, we extrapolate the number of awakenings from church bells to the whole population and compare their overall impact with the impact from aircraft noise. The findings could provide the foundations for the regulation of church bell noise during nighttime in Switzerland.

# Nocturnal road traffic noise and sleep: location of the bedroom as a mediating factor in the subjective evaluation of noise and its impact on sleep

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## INTRODUCTION

The impact of noise intrusion on sleep and daytime functioning is well illustrated in the literature, where results of both laboratory and field studies are reported (Griefahn 2002; Muzet 2007). One challenge in the elaboration of field studies on the impact of road traffic noise on sleep concerns the indoor noise assessment. Only a few field studies assessed indoor noise levels on a daily basis (Eberhardt & Akselsson 1987; Vallet et al. 1983). Other large-scaled field studies – though showing consistent results for sleep disturbances - were unable to collect individual noise levels due to large population samples and therefore needed to rely on outside noise measurements (Öhrström 1991 & 1989; Belojević & Jakovljević 1997; Stošić et al. 2009). Another element that complicates field studies on noise and sleep is the fact that in addition to noise exposure, a large number of mediating factors play an important role in the contribution of noise to sleep disturbances (Ouis 2001; Muzet 2007). Of the many mediating factors investigated, little research was performed on the effects of the bedroom location on the relation between inside and outside noise levels, on noise perception and on sleep disturbances in highly noise exposed regions. One study performed by Öhrström (1993) reported a decrease in sleep quality, longer sleep onset latencies and lower values in terms of psycho-social wellbeing in subjects sleeping at the street side compared to subjects sleeping at the backside of their houses, both located in high density of road traffic regions. In most studies, this issue is addressed by putting the bedroom orientation as an inclusion criterion (e.g. all street side) or by measuring noise levels outside at the bedroom façade (Öhrström 1991; Öhrström & Skånberg 2004; Stošić et al. 2009). Other studies derived the bedroom location from questionnaires and corrected the noise levels outside according to it (Öhrström 1989, 2004; Belojević & Jakovljević 1997).

This sub-study is a part of a longitudinal study investigating the relationship between nocturnal road traffic noise, sleep quality and general well-being of inhabitants of the Brussels' Capital Region. In this study, results of the assessment of differences in outside as well as inside noise levels according to the bedroom location are presented. We also investigated in what extent the location of the bedroom influences the traffic noise perceived during the night and its impact on sleep.

## METHOD

### Study population

Subjects were recruited by mailing in the so-called "black spot" regions in Brussels. These regions were already defined and mapped by the Brussels Institute for Management of the Environment (BIME). "Black spots" are defined as 'Residential or building areas with either a concentration of various types of noise pollution or a high number of complaints concerning noise pollution' (www.leefmilieubrussel.be). An additional screening of those regions was performed so a maximum of confounding variables such as noises from pubs, restaurants and others could be avoided.

21 subjects were included in this study and were divided in two groups according to their bedroom orientation. In the first group, eight subjects (6 males, 2 females, average age 45 years) had their bedrooms located at the street side. 50 % lived in apartments (1$^{st}$ to 3$^{rd}$ floor), 37 % in enclosed houses and 13 % in semi-detached houses. 88 % of the bedroom places had double-glazed windows. The second group consisted of thirteen subjects (9 females, 4 males, average age 40 years) sleeping at the backside of their apartments (85 %, ground floor to 8$^{th}$ floor) or enclosed houses (15 %). 85 % of the bedroom places had double-glazed windows.

Inclusion and exclusion criteria were a good general health, a regular sleep-wake schedule, no children or children above 10 years of age, no shift or night workers, no pregnancy, no alcohol consumption of more than 15 units a week and no medication that alters sleep such as hypnotics, antidepressants or tranquilizers. Also, all subjects lived in noisy regions for at least one year.

### Nocturnal road traffic noise

Traffic noise was recorded inside and at the outside façade of each bedroom place during five consecutive nights. We used an Integrator Class 1 (inside) and Class 2 (outside) Sound Level Meter (SLM; Metravib®) with a measurement range of respectively 20-137 dBA and 30-137 dBA. For the outside SLM, we attached the microphone at the outside façade of each bedroom place with a distance of ± 0.5 m from the window, using balconies or other possibilities and taking into account safety measures for vandalism or robbery. The indoor SLM was installed in the bedroom, where possible near the head of the bed and according to the accessibility for power supply. A mean noise level value per 30-second was recorded from 22 PM to 08 AM. Noise data were analysed with the software program dBTrait (version 4.805).

### Sleep logs and subjective evaluation of nocturnal road traffic noise

Sleep logs were completed every morning during five days. Questions included time to go to bed, time of lights out, an estimation of sleep onset latency (SOL), estimation of the number and reason for awakening during the night, time of wake up and subjective evaluation of sleep quality (SQ; 1 = very bad sleep; 2 = rather poor sleep; 3 = slept reasonably well; 4 = slept very well). Sleep parameters analyzed in the framework of the current paper were SOL and SQ.

For the evaluation of the experienced nocturnal noise, a visual analog scale (VAS) was used. Subjects were asked every morning to rate their degree of disturbance due to noise on a 100 mm line ranging from 0 to 10. Additionally, questions on the source and the frequency of occurrence of the noise sources were included.

This study was approved by the Ethics Committee of the Free University of Brussels. Data recording took place from 9/2006 till 5/2007. Holiday and weekend periods were excluded due to the diminished road traffic volume. Weekdays are defined as Monday referring to the night from Sunday to Monday and accordingly for the rest of the week.

## Analysis and statistical design

For the noise analyses, we calculated $L_{Aeq}$, $L_{Amax}$ and number of noise events of the inside and outside noise measurements from 23 PM to 07 AM. The noise events were categorized in accordance with the sleep disturbances and health effects observed in the population as described by the WHO (2009).

Range 1: noise events from 30 dBA to 40 dBA: Increase in primary sleep disturbances.

Range 2: noise events from 40 dBA to 55 dBA: Sharp increase in adverse health effects in a large part of the exposed population.

Range 3: noise events above 55 dBA: Adverse health effects occur frequently.

As not all of the data sets appeared normally distributed and both groups consisted of small study samples, non-parametric Mann-Whitney U Tests were used to compare $L_{Aeq}$, $L_{Amax}$ and number of noise events, the sleep variables SOL and SQ and the mean scores of the VAS. Chi-square tests were used to compare detailed results of the VAS.

RESULTS

## Noise measurements

Table 1 represents an overview of the mean noise levels in $L_{Aeq}$, $L_{Amax}$ and number of noise events measured inside and outside the bedroom place located at the street or at the backside of the dwelling. For the outside noise measurements, all noise indicators - with the exception of the lower range of noise events - were statistically significantly different with higher noise levels measured at the street side compared to the noise levels at the back side. This was however not the case for the inside noise levels, where no differences between the noise levels at the street and the backside could be found. For the number of noise events inside in range 3 (above 55 dBA), we found them in more than 50 % of the nights to be absent so no further analysis was performed.

**Table 1:** Overview of the mean noise levels per noise indicator inside and outside the bedroom at the street and backside and their significance level

| Noise indicator | Street side | Backside | p level* |
|---|---|---|---|
| $L_{Aeq, outside, 23-07}$ | 66.1 dBA *(65.5 – 66.8 dBA)* | 50.5 dBA *(48.7 – 51.7 dBA)* | <0.001* |
| $L_{Amax\ outside, 23-07}$ | 84.2 dBA *(80.5 – 86 dBA)* | 69.4 dBA *(65.6 – 70.5 dBA)* | <0.001* |
| Noise events, outside R1: 30-40 dBA** | 0.9 % *(0.2 - 1.6 %)* | 12.5 % *(5.7 - 15.4 %)* | 0.10 |
| Noise events, outside R2: 40-55 dBA** | 24.7 % *(19.2 - 28.7 %)* | 81.6 % *(76.7 - 90.8 %)* | <0.0001* |
| Noise events, outside R3: above 55 dBA** | 74.8 % *(69.7 - 80.6 %)* | 5.3 % *(2.9 - 9.2 %)* | <0.0001* |

| Noise indicator | Street side | Backside | p level* |
|---|---|---|---|
| $L_{Aeq, inside, 2307}$ | 38.4 dBA *(36 – 40.7 dBA)* | 40.1 dBA *(36.9 – 42.3 dBA)* | 0.59 |
| $L_{Amax, inside, 23-07}$ | 62.6 dBA *(57 – 66.8 dBA)* | 59.2 dBA *(55.2 – 61 dBA)* | 0.59 |
| Noise events, inside R1: 30-40 dBA** | 39.6 % *(37.5 – 40.9 %)* | 31.9 % *(23.8 - 38.1 %)* | 0.50 |
| Noise events, inside R2: 40-55 dBA** | 5 % *(4.1 - 5.8 %)* | 6.2 % *(5.5 - 7.1 %)* | 0.46 |

* p-level statistically significant at .05
** Mean percentage of number of epochs in which noise events occur relative to the total number of epochs over a complete night.

### Subjective evaluation of noise disturbances

The average results of the subjective evaluation of noise disturbances and the report of specific noise sources during the night are summarized in Table 2. No significant differences were found in the overall evaluation of noise disturbances during the night. For the specific noise sources, significantly more disturbance due to road traffic noise was reported in subjects having their bedroom located at the street side. Also, significantly more quiescence was reported by subjects sleeping at the backside of their dwelling.

**Table 2:** Weekly average score of level of overall noise disturbance and percentage of participants subjectively reporting specific noise disturbances during the night as assessed with the VAS

| | Street side | Backside | p-level* |
|---|---|---|---|
| Mean score/10 | 1.5 | 1.6 | 0.45 |
| **Noise sources** | | | |
| *- Traffic noise* | 23 % | 8 % | 0.003* |
| *- Other noise outside* | 13 % | 11 % | 0.66 |
| *- Noise inside* | 19 % | 15 % | 0.45 |
| *- Not specified* | 18 % | 9 % | 0.06 |
| *- No noise* | 40 % | 60 % | 0.004* |

** p level statistically significant at .05.*

### Evaluation of sleep logs

The results of the sleep logs revealed that both groups reported the same levels of sleep quality; they slept rather well ($U = 51$; $p>.05$). A significant difference was found in the comparison of the sleep onset latency between both groups ($U = 19.5$; $p<0.05$). Subjects sleeping at the street side of their dwellings took on average 32.6 minutes to fall asleep compared with 12.0 minutes for the subjects sleeping at the backside.

## DISCUSSION

Contrary to the outside noise levels, which were clearly distinct between both groups, no significant differences were found for the indoor noise levels in all noise indicators investigated. This finding might have some methodological implications, as in most studies, the determination of indoor noise levels relies on outside noise assessment or estimations based on outdoor measurements in reference areas (Belojević & Jakovljević 1997; Stošić et al. 2009). One of the primary interests in research on the effects of noise intrusion on sleep concerns the actual indoor noise levels, which are perceived by the subjects during the night. Having exact information on the indoor noise levels permits an establishment of direct relationships between noise exposure and sleep disturbances. The present findings suggest that caution is needed concerning this issue as the large discrepancy in outdoor noise levels between bedrooms located at the street side in comparison with the backside, is not necessarily reflected in lower noise levels reaching the inside of the bedrooms located at the backside as compared to the street side.

Although no differences in indoor noise levels were found, the results of the subjective evaluation of noise disturbances during the night revealed that subjects sleeping at the street side were significantly more disturbed by noise originating from road traffic. Furthermore, subjects sleeping at the street side had a sleep onset latency which was on average 20.6 minutes longer compared to subjects sleeping at the backside. This finding is similar with the results found in the study performed by Öhrström (1993). However, contradictory results compared with this study were found for the evaluation of sleep quality, which in our study did not differ between both groups.

As a small number of subjects participated in this study, generalizations must be drawn with caution. We can conclude from this study that the role of the outside noise on the overall perception of sleeping at the street side in noisy regions is of importance as it clearly - but indirectly as no differences in indoor noise levels were found between both groups - impacts sleep onset latency. The reported sleep quality was however not influenced by the prolonged sleep onset latency. Also, with this study we demonstrated and confirmed the importance of incorporating the bedroom location as a mediating factor of outside noise levels in the elaboration of field studies on noise and sleep disturbances. Finally, this study stresses the need for adequate indoor noise assessment as the magnitude of the difference in inside noise levels between street and backside oriented bedrooms might not be as pronounced as often assumed based on outdoor measurements and thus creates a risk for biasing interpretation of research outcomes.

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# Team 6 activities from 2008 to 2011

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## INTRODUCTION

Team 6 discussed the activities from 2008 to 2011 at ICBEN Congress 2008. One collaborative theme and eight individual research projects were proposed: (1) the prevalence of guidelines for reporting core information from community noise reaction surveys, (2) combined effects of noise and vibration, (3) difference in response between standardized 5-point verbal and 11-point numeric scales, (4) how to estimate noise exposure and extract dose-response relationships, (5) establishment of data archive of socio-acoustic surveys, (6) linkage with soundscape research, (7) cross-cultural surveys particularly in developing countries, (8) noise change study and (9) cooperation with Team 9. The outcomes from these activities are summarized.

## TEAM 6 ACTIVITIES FROM 2008 TO 2011

### Guideline for reporting core information from community noise reaction surveys

In order to precisely compare the findings and results from community noise reaction surveys, Team 6 proposed the guideline for reporting core information from socio-acoustic surveys (Fields et al. 1997) and standardized noise annoyance scales in nine languages (Fields et al. 2001), respectively. These outcomes are included in ISO TS/15666. The latter is quite successful because the scales have been used in many surveys since the publication. The scales in the other languages have also been constructed (Preis et al. 2003; Yano & Ma 2004; Kvist & Pedersen 2006; Guenther et al. 2007). However, the former is not prevalent. Thus Team 6 asked J.M. Fields to make simplified tables for core information to be shown in journal articles and conference papers. Tables 1 and 2 are those for journal articles and conference papers, respectively. We sent two tables to international researchers who are engaged in community noise reaction surveys and asked them to use these guidelines in their own, their colleagues' and their students' papers. These tables are in the homepage of ICBEN: http:www.icben.org/.

### Other eight themes

In total 37 abstracts were submitted to Team 6 session. From these submissions four papers were selected for the plenary session. Community response to noise research should be carried out cross-culturally and longitudinally since community response to noise may be a function of time and space. The two studies propose annoyance models and the other two discuss cross-cultural issue of railway bonus and effects of noise change on annoyance.

**Table 1**: Journal reporting guidelines

| Topic area | Item | Topic | Information |
|---|---|---|---|
| Overall survey design | 1 | Survey date | Year and months when the social survey information was obtained from respondents |
| | 2 | Site location | The country & community(s) where the study sites were located and any important, unusual characteristics of the study period or study sites |
| | 3 | Site selection | The rationale and method for selecting study sites including all criteria that were explicitly used to select or exclude possible study sites |
| | 4 | Site size | The number of sites, areas, or locations where the social survey was conducted |
| | 5 | Study purpose | * The goals and purposes for conducting the study<br>* The name of the organization that sponsored the survey |
| Social survey sample | 6 | Sample selection | The general method for selecting respondents (probability, judgmental, etc.), the detailed procedures that were followed and any criteria, that were followed to exclude some people in the study area (for example: age, gender, length of residence, etc.) |
| | 7 | Sample size (Issued) | A survey response rate and reference to the exact formula and operational definitions that were used to calculate the response rate. (Standard response rate formulas for most designs are defined in detail at http://www.aapor.org/standarddefinitions) |
| Social survey data collection | 8 | Survey methods | The method used to obtain respondents‘ answers (Face-to-face interviews, telephone interviews, mail surveys, etc.). If interviewers are used, the training and qualifications of the interviewers are provided |
| | 9 | Questionnaire wording | Exact wording of survey questions in the respondents' language and translated into language of the publication for annoyance questions and any other questions that were analyzed for the publication |
| | 10 | Precision of sample estimate | The number of respondents who provided answers that could be used in the analysis. The confidence intervals and results of significance tests for major results reported in the article |
| Nominal acoustical conditions (i.e., the common reference positions and conditions that the acoustical estimates represent) | 11 | Noise source | The primary noise source studied (aircraft, road traffic, etc.) and any types of noise, types of operations or noise levels from that noise source that are not included in the reported noise exposure values |
| | 12 | Noise metrics | The complete, standard label for any noise metrics appearing in the article. If these metrics are not $L_{Aeq24hr}$, DENL and DNL, then an appropriate conversion rule should be given for estimating $L_{Aeq24hr}$, DENL, and DNL from noise metrics used in the article |
| | 13 | Time period | The time period that the noise metric represents, in terms of hours of the day, and number of days or months that the reported noise exposure values are assumed to represent |

| | | | |
|---|---|---|---|
| | 14 | Estimation/ measurement procedure | If the respondent's noise exposure is estimated, describe or cite the noise prediction model version. If the exposure is measured, describe the sound sampling, measurement and estimation protocols |
| | 15 | Reference position | The reference position for which the noise exposure values are normalized relative to the noise source and reflecting surfaces and a conversion rule for estimating the exposure at the noisiest facade of the respondent's dwelling excluding sound reflected from the facade |
| | 16 | Precision of noise estimate | Provide the best information available about accuracy of noise exposure estimates for the periods they nominally represent. Describe any unusual factors that affected the accuracy or ability to estimate long-term noise exposure |
| Basic dose/response analysis (if a study goal) | 17 | Dose/response relationships | Present a tabulation of each degree of reaction for each category of noise exposure |
| Explanatory variable analysis (if part of study objectives) | 18 | Non-noise variables' impacts on reactions (e.g., demographic, personal or community variables) | Present the size of each non-noise variable's effect controlled for noise level and in units or graphs that permit comparisons to the size of effects from noise exposure. Conclusions should be reported for all variables, even if no statistically significant effect is found.<br>- Compare the ability of noise level alone and of all explanatory variables together to explain response (e.g., correlation ($r^2$) and multiple correlation coefficient ($R^2$)) |

**Table 2**: Conference reporting guidelines

| **Topic area** | **Item** | **Topic** | **Information to include** |
|---|---|---|---|
| Overall survey design | 1 | Survey date | Year and season when the social survey information was obtained from respondents |
| | 2 | Site location | The country & community(s) where the study sites were located |
| | 3 | Site selection | The rationale and method for selecting study sites |
| | 4 | Site size | Number of sites, areas, or locations where the social survey was conducted |
| | 5 | Study purpose | The name of the organization that sponsored the survey |
| Social survey sample | 6 | Sample selection | The method for selecting respondents (random/probability, judgmental, etc.) |
| | 7 | Sample size (Issued) | The number of sampled people or dwellings where an attempt was made to find a person who would answer the survey questionnaire |
| Social survey data collection | 8 | Survey methods | The method used to obtain respondents' answers (Face-to-face interviews, telephone interviews, mail surveys, etc.) |
| | 9 | Questionnaire wording | The exact wording of the primary questionnaire items (including answer alternatives) |
| | 10 | Precision of sample estimate | The number of respondents who provided answers that could be used in the analysis |
| Nominal acoustical conditions (i.e., the com- | 11 | Noise source | The primary noise source studied (aircraft, road traffic, etc.) |
| | 12 | Noise metrics | The complete, standard label for any noise metric appearing in the conference paper |

| Topic area | Item | Topic | Information to include |
|---|---|---|---|
| mon reference positions and conditions that the acoustical estimates represent) | 13 | Time period | The period (hours of the day) that the noise metric represents |
| | 14 | Estimation/ measurement procedure | The method used to derive the noise exposure levels for each respondent (modeling, measurement during sampled periods, etc.) |
| | 15 | Reference position | The reference position for which the noise exposure values are normalized relative to the noise source and reflecting surfaces (e.g., one meter from the noisiest facade, etc.) |
| | 16 | Precision of noise estimate | Any unusual factors that affected the accuracy or ability to estimate long-term noise exposure |
| Basic dose/response analysis (if part of study objectives) | 17 | Dose/response relationships | A measure of the extent of the response within each noise exposure grouping |
| Explanatory variable analysis (if part of study objectives) | 18 | Non-noise variables' impacts on reactions (e.g., demographic, personal or community variables) | The conclusions reached about the effect or lack of effect of each demographic, personal, or community variable examined (even if no effect is found) |

## ACKOWLEGEMENT

The authors appreciate Dr. J. M. Fields for making the simplified tables for the core information and Dr. T. Gjestland for his appropriate advises for Team 6 activities from 2008 to 2011.

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# Community response to noise - A theory-based model for exposure-response relationships

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## INTRODUCTION

Dose-response functions that relate transportation noise exposure to the average annoyance experienced by the residents in a community are important tools for city planners. Normally one would want to keep the negative impact from transportation noise as low as possible. However, a “zero target” is seldom feasible. A reliable dose-response function will tell which noise exposure level that is “low enough” to keep the annoyance at an acceptable level.

Since the initial effort by T. J. Schultz to establish a dose-response function for transportation noise (Schultz 1978) numerous attempts have been made to refine and improve such functions. Most of these dose-response functions have been derived by applying more or less sophisticated mathematical and statistical methods to a set of observation data coming from social surveys. Regression analysis is a statistical technique that can identify a function which minimizes the sum of the squares of the distances of a set of points to a line or a curve. A dose-response relationship derived by regression yields a function appropriate for characterizing annoyance prevalence rates of nominal communities located in the middle of a cloud of data points.

If the data points represent noise exposure (x-axis) and prevalence of annoyance (y-axis) the regression can either predict noise exposure from annoyance, or annoyance from noise exposure. Cause and effect are irrelevant in this analysis.

## PREVIOUS STUDIES

Figure 1 shows a selection of “approved” dose-response functions for aircraft noise annoyance. The first serious attempt to establish a dose-response curve for transportation noise annoyance was published by in 1978 (Schultz 1978) Schultz’s synthesis was based on a number of social surveys, mainly on road traffic noise. However, some studies on railroad noise and aircraft noise were also included. Schultz concluded that there was no difference between these sources. His dose-response function, the dark blue line in Figure 1, is based on 161 data points.

Later more surveys were added to the common data base, and in 1992 FICON (FICON 1992) established a “new and improved” dose-response curve for aircraft noise annoyance. This curve was based on about 400 data points. This function, the yellow line in Figure 1, shows only slight deviations from the original “Schultz curve”.

The generally accepted international standard for assessing community noise annoyance, ISO 1996, Pt. 1, (ISO 2002) has yet another dose-response function. This is the same as the original Schultz curve from 1978, but the noise level has been given a source dependent correction. The standard recommends a “correction penalty of 3 to 6 dB”. This means that road traffic at for instance 60 dBA is considered equally annoying as aircraft noise at a level between 54 dBA and 57 dBA. The red line in Figure 1 shows the dose-response function according to ISO with a 6 dB penalty.

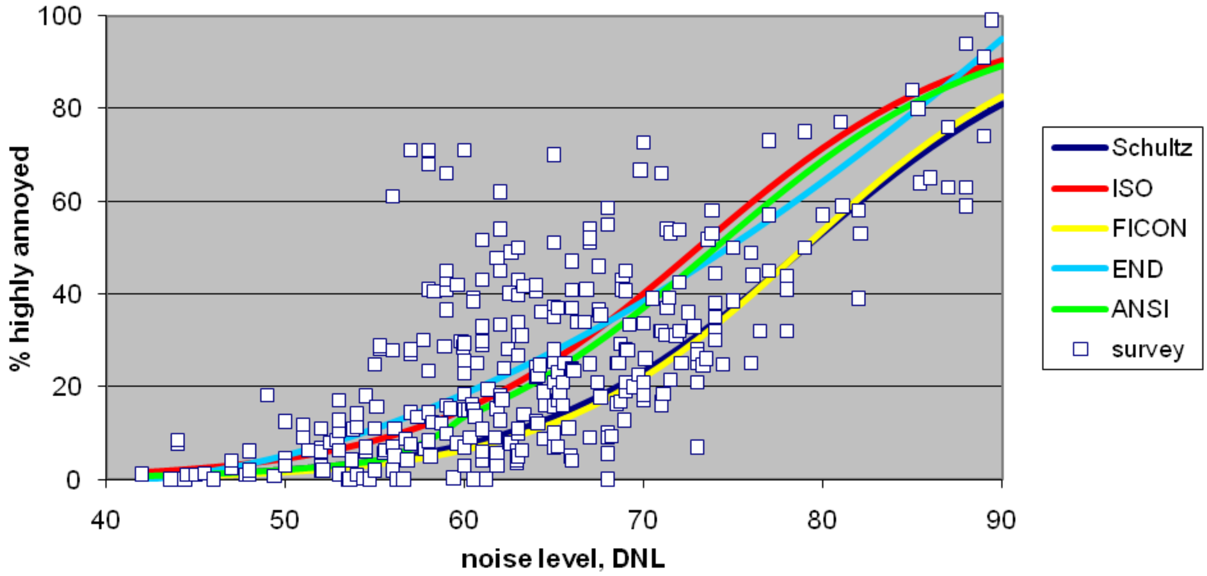


**Figure 1:** Various "standardized" dose-response curves for aircraft noise annoyance plotted against the results from 24 different surveys

The American National Standards Institute uses a similar approach in their standard for assessing community response to long term noise exposure, ANSI 12.9, Pt. 4 (ANSI 2005). In this standard the dose-response for aircraft noise annoyance is also based on the original Schultz curve from 1978, but the suggested aircraft noise penalty is level dependent. For noise levels below 55 dBA the correction is 0 dB and for noise levels above 60 dBA a 5 dB penalty is applied. In the transition interval there is a gradually increasing penalty from 0 dB to 5 dB. The dose-response function according to ANSI 12.9 is shown as a green line in Figure 1.

In 2002 the European Union adopted a noise directive, END, dealing with community noise annoyance. A background paper for this directive was a study by Miedema & Vos (1998) who developed a set of dose-response functions for aircraft, road traffic and rail noise. The aircraft noise analysis was based on 19 studies and more than 27,000 observations. The relevant function for "percentage highly annoyed by aircraft noise" is shown as a light blue line in Figure 1.

The five curves in Figure 1 represent different possible dose-response functions for aircraft noise annoyance. They are to a large extent based on the same survey data, but different assumptions during the analysis yield quite different results. The differences are especially prominent in the noise level range 55 dBA to 75 dBA, which is the most relevant for regulatory purposes.

## A NEW APPROACH

The result of a regression analysis gives a "best fit" function based on the available input data, but this function does not explain the relationship between the independent and dependent variables. A very different approach to establishing a dose-response function would be to develop a model based on for instance physics and well known psychological inter-relationships, and then check how well the observation data from the surveys fit this model.

Some established findings regarding the relationship between noise exposure and annoyance include the following:

- Duration is a fundamental difference between loudness and annoyance. Once a sound attains a duration of about 250 milliseconds, the sensation of loudness remains stable, but its annoyance increases, at a rate of 3 dB per doubling of duration.
- It has been known for more than half a century that loudness grows as the 0.3 power of acoustic energy. This fact is the basis for the well-known rule of thumb that loudness changes by a factor of two for every 10 dB change in sound level.
- It has also been well understood since the first modern social survey of the annoyance of aircraft noise in 1961 that annoyance prevalence rates are dependent in part on non-acoustic factors.

From laboratory studies that involve assessment of noise samples it is a well known fact that loudness is a very critical and dominating parameter. There are therefore reasons to believe that loudness also plays a big role in the assessment of annoyance in a community noise situation. Since annoyance is closely related to duration-adjusted loudness, it is reasonable to assume that the basic growth rate of annoyance with exposure should be that of duration-adjusted loudness. An estimate of the effective loudness of noise exposure can thus be derived by transforming Day-Night Average Sound Levels into a duration-adjusted dose, *m*, to convert pressure units into a quantity proportional to loudness:

$$m = (10^{(DNL/10)})^{0.3}$$

Fidell, Schultz, and Green (Fidell et al. 1988) noted that social survey respondents' self-reports of their attitudes reflect both their community's transportation noise exposure and a reporting criterion. The more stringent the criterion for reporting annoyance is in a given community, the farther it slides the effective-loudness function to the left (lower levels). The more lenient the criterion is, the farther it slides the effective-loudness function to the right (higher levels).

Predicted annoyance prevalence rates for the calculated dose may be computed as $p(HA) = e^{-(A/m)}$, where A is a non-acoustic decision criterion, *per* Green & Fidell (1991). This exponential function provides a single parameter transition function to describe the change of the proportion of the residents of a community that are "highly annoyed".

This is where the new method departs fundamentally from regression analysis. In regression analysis, a curve is sought which is closest on average to all of the data points. In the new proposed method, the goal is to select the value of A which best describes the fit of the data from a particular community to an *a priori* transition function.

The community-specific constant, A, is found by minimizing the root-mean-square deviation of the annoyance prevalence rates observed at the interviewing sites in each community from those predicted by an exponential function with a slope equal to the rate of growth of loudness with level ("the effective loudness function"). This process slides the effective loudness function along the DNL axis to the point at which a best fit between the predicted and observed points occurs. The value of A that yields the best fitting value for a community's response data to the effective loudness function may then be linearly transformed into a value on the exposure axis that reflects the aggregate influence of all non-DNL related factors on annoyance judgments in a given set of field observations.

One minor complication arises when the family of curves described by the function $e^{-(A/m)}$ is applied to individual communities. The complication is finding a standard way to anchor the curve to a point on the DNL axis so that its position can be easily described. A simple solution is to pick some point on the function, and refer to the abscissa value, the DNL value, at that point. For reasons of convenience, the "middle" of the function – the point at which half of the people in the community describe themselves as highly annoyed by noise exposure, and half do not – is an obvious choice. The value of DNL that corresponds to the middle of the effective-loudness function for a given community may be thought of as a measure of how tolerant the community is toward noise exposure, or as a Community Tolerance Level (abbreviated "CTL", and represented symbolically in mathematical expressions as $L_{ct}$).

Results from social surveys indicate that in some communities half of the residents may not be highly annoyed until DNL reaches a level in the 80 dB range. These communities may be described as "very tolerant to noise". In other communities the 50 % point for highly annoyed may be in the DNL 60 dB range. These communities have "a low tolerance for noise". In Figure 2 the CTL-method has been applied to the results from several aircraft noise studies. The CTL values vary from 63 dB (Frankfurt) to 84 dB (Heathrow).

In Figure 3 the CTL-method has been applied to the combined data sets from 43 different aircraft noise surveys. The grand mean of the CTL values is 73.3 dB.

Figure 4 compares this dose-response relationship with that derived by Miedema & Vos (1998). Miedema and Vos have based their calculations on practically the same data sets. The two curves are nearly identical in the noise exposure range of primary interest.

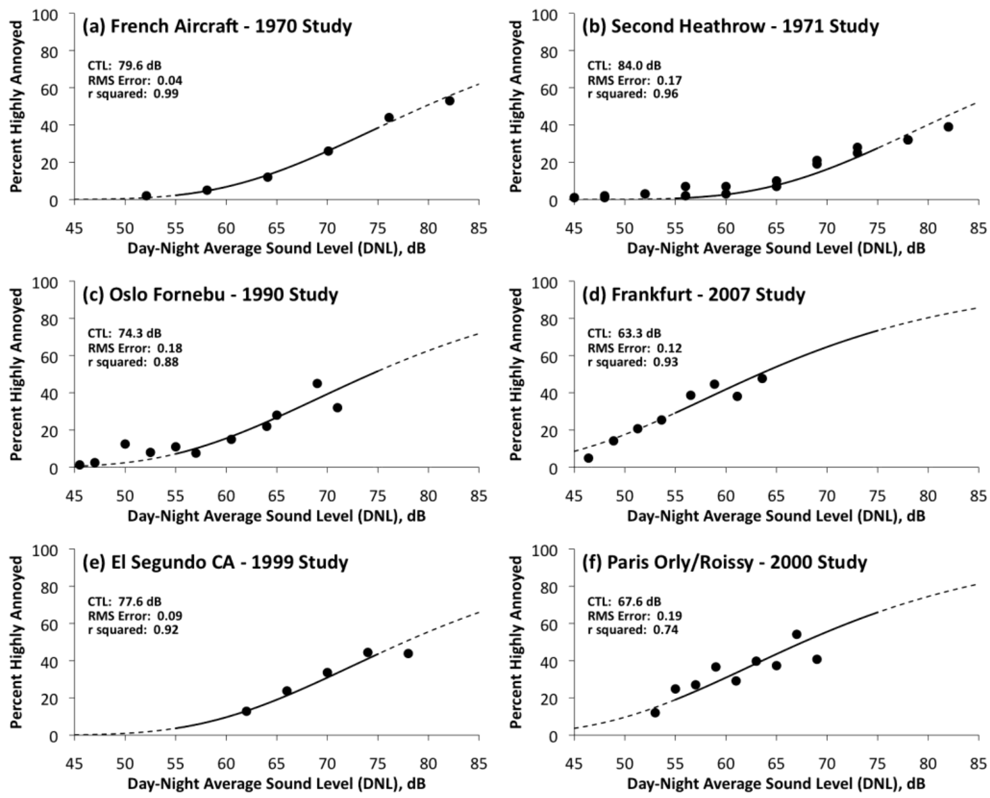


**Figure 2:** Fits of community response data for several surveys on aircraft noise annoyance

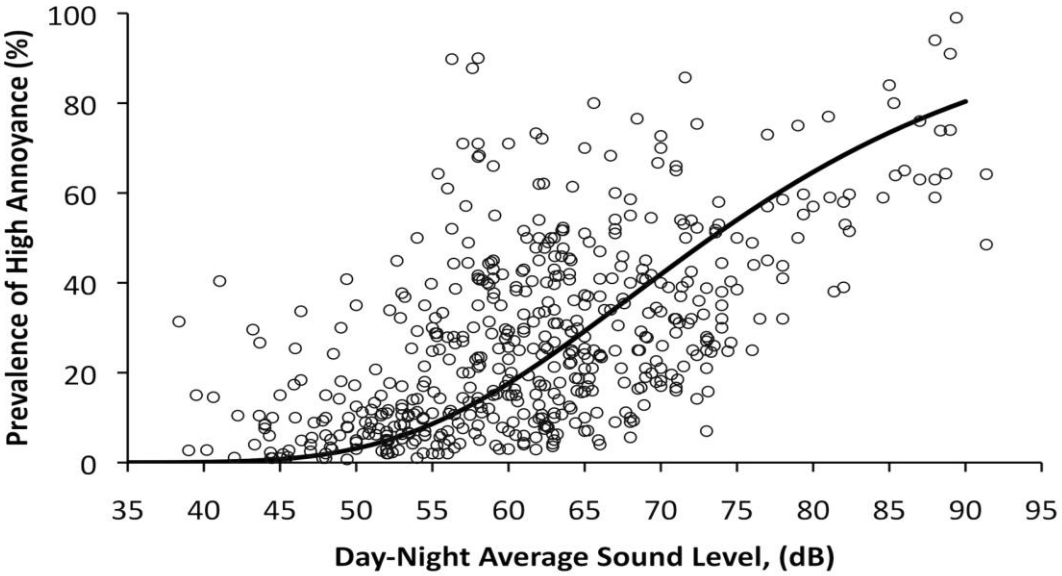


**Figure 3**: Fit of 43 aircraft annoyance data sets to effective loudness function for a CTL value 73 dB

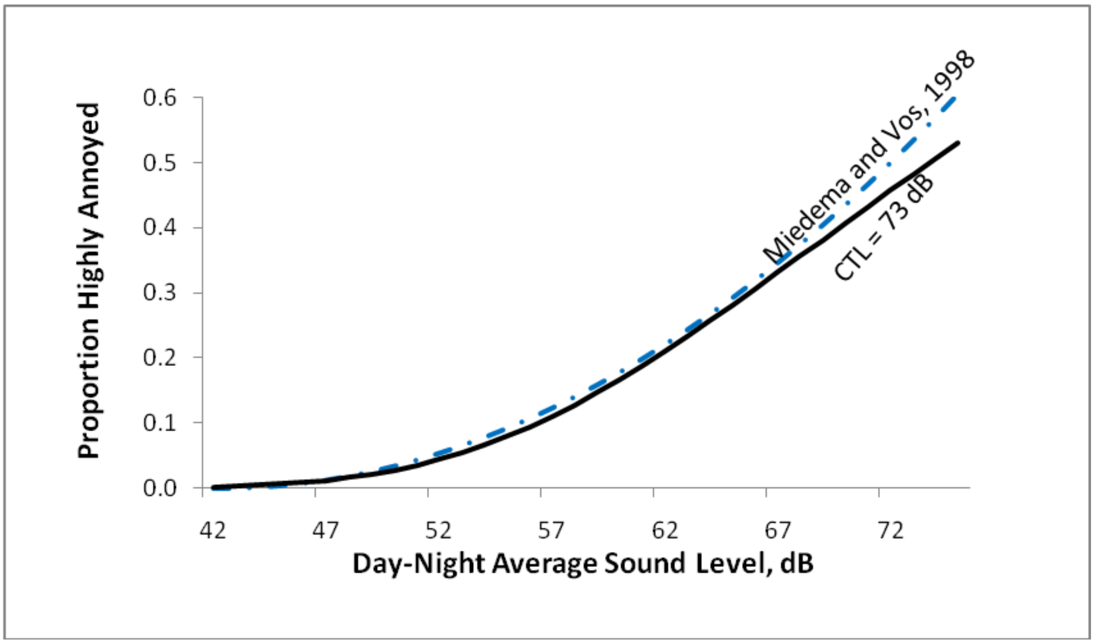


**Figure 4:** Comparison of two dose-response curves for aircraft noise annoyance

## CONCLUSIONS

The present findings indicate that the prevalence of annoyance with transportation noise in communities may be usefully predicted from 1) estimates of the duration-corrected loudness of noise exposure, and 2) estimates of community-specific tolerances for noise exposure. The relationship between average annoyance prevalence rates and noise exposure derived as described above closely resembles dose-response relationships for transportation noise derived by Miedema & Vos (1998) by regression analysis. This close resemblance provides further pragmatic reason to believe 1) that the dose-related determinants of annoyance are driven by duration-corrected loudness, and 2) that when applied to any given community, predictions of response to transportation noise exposure which are derived from generic statistical analyses must be adjusted by the tolerance of that community for noise exposure.

A more detailed presentation of the proposed method backed by calculation examples based on previous annoyance studies of transportation noise can be found in Fidell et al. ( 2011) and Schomer et al. (2011).

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# Biologically inspired modeling of environmental noise perception

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## INTRODUCTION

Although it has been mentioned by many authors that spectro-temporal details and informational content have a significant influence on the perception of environmental sound, most models for annoyance and health effects ignore this fact and treat environmental noise in a simple dose related manner. Over the years we followed a different modeling approach solidly grounded in known psychoacoustical and physiological effects. Several generations of biologically inspired models – that are suitable for typical environmental noise assessment applications – were designed. The importance of noticing the sound was recognized in a notice-event model. This model was later extended with an activation and inhibition based attention module accounting for both saliency triggered attention and prolonged outward oriented attention focusing. Finally aspects of sound identification and stream formation were added. The latter is enhanced by including binaural effects. The models for binaural and monaural stream segregation rely strongly on artificial neural networks, trained both in an unsupervised and in a supervised way. The biologically inspired models for environmental noise perception have been applied to assess both synthetic (modeled) combinations of sound and recorded sound mixtures.

## COMPUTATIONAL MODELS FOR ENVIRONMENTAL NOISE PERCEPTION

### Temporal aspects and noticing sounds

For most people, exposure to environmental noise varies a lot over the day. To some extent this is due to the variation in sound sources, but more importantly the person at the receiving end is moving around and producing noise itself (Diaz & Pedrero 2006) by engaging in various activities. When investigating – across source type – temporal sound patterns, it becomes obvious that environmental sounds very seldom have constant levels. Moreover, on the short temporal scale, combined exposure generally turns out to be a sequence of sounds from various sources, dominating the sonic environment one at the time. Based on these observations it can be concluded that, on a short – one second – temporal scale, a statistical approach could be a useful addition to modeling the perception of environmental sound. Calculating the probability that a sound is loud while a person’s personal noise is low and attentiveness is high could give some indication on how sounds with a different temporal pattern are perceived. However, this ignores the duration of single noise events and potential adaptation and habituation to continuous sound. Therefore, within the notice-event model (De Coensel et al. 2009), complete time sequences are simulated for the total duration of the observation, or for at least a representative sample of it. To group consecutive time segments into a single perceptual notice-event, relaxation mechanisms with time constants inspired by psychoacoustical lab experiments are used. The outcome of such a model could be the fraction of the time that a sound is noticed over the course of a day, or the sound level during notice-events. Both could also be considered as indicators of annoyance at home (Bockstael et al. 2011).

**Including spectral effects and attention mechanisms**

A second important observation regarding the perception of environmental sound was introduced in a second generation model. While attending to daily activities or while relaxing in a tranquil environment, listening to environmental sound is seldom the primary objective. Thus, environmental sound has to attract attention before it is consciously perceived and judged either positively or negatively. The sensory driven (bottom-up) part of the human auditory attention mechanism relies heavily on spectro-temporal changes in the sound. Hence, a model for environmental sound perception should account for the saliency (Kayser et al. 2005) in the sound. In the implemented model, auditory saliency is estimated through the calculation of a saliency map, which emphasizes those time-frequency units that are most likely to be the subject of auditory attention. In parallel, target sounds are compared to all other acoustic stimuli on the basis of time-frequency masks, accounting for energetic masking. Finally, by combining both the above time-frequency maps, a time-varying saliency score is calculated for each target sound (De Coensel & Botteldooren 2010).

When implementing a model for environmental sound perception that includes attention mechanisms (Knudsen 2007), accounting for inhibition of return (Spence & Driver 1998) is essential. This mechanism prohibits that a sound with a high saliency would attract attention continuously. Four time constants are needed to include the dynamics of this activation-inhibition mechanism into the model: a fast increase of activation when a salient sound appears, followed by a somewhat slower inhibition rise, and finally a slow decay of inhibition and activation to allow renewed attention at a later stage. The choice of these time constants is inspired by biology (e.g. Lagemann et al. 2010). In addition the model has to account for other stimuli (including non-auditory), in order for attention to be drawn away from the sound in a winner-takes-all competing scheme. Top down attention for particular sounds that carry the listener's interest is modelled as a bias on attention activation for this particular acoustic stream.

Including the above mentioned mechanisms in the model automatically yields a model in which auditory effects such as energetic masking, informational masking (Watson 2005) and sensory adaptation emerge. The fact that these effects emerge on a macroscopic scale partly validate the model.

**Stream segregation and source identification**

One of the most challenging tasks in modelling the perception of environmental noise lies in automating auditory scene analysis and the resulting auditory stream formation. Although the theoretical understanding of the biological mechanisms involved remains a point of debate, the choice of auditory features is without doubt an important first step. Most of the work in this area is related to speech and some researchers have indeed applied the typical features also to environmental sound (Cowling & Sitte 2003). Here we suggest a different approach based on simple features that have a biologically plausible counterpart, combined with a strong learning of temporal coherence in the past. The importance of temporal coherence in auditory scene analysis and learning has recently been confirmed on a neurological basis (Shamma et al. 2011). In the model we use a self organising map (Oldoni et al. 2010) to group features in the multi-dimensional space. After training, each area in this two-dimensional representation corresponds to sounds with similar acoustic features. A new sound presented to the model will then map to a particular area in this two dimensional map at any particular time.

Creating streams by connecting the excitation of auditory features over time remains a difficult task. A sound may be temporally masked in feature space by another sound of short duration, yet a human observer is perfectly capable of connecting the parts before and after masking. The role of attention in this process could be important. The best monaural model that could be implemented thus far is based on locally excitatory globally inhibitory oscillator networks (LEGION), proposed by Wang and Chang (2008). In contrast to the work by these authors, the proposed model operates LEGION on the outcome of the self organised map rather than on the time-frequency spectrum itself, which reintroduces time as an additional dimension.

### Binaural aspects of stream segregation and attention focussing

When sound sources are spatially separated, auditory stream segregation in normal hearing listeners is improved a lot by binaural listening. Consequently, a model based on binaural recorded or simulated sound should be more capable of identifying sound objects. The biologically inspired model that is proposed (Boes et al. 2011) is based on binaural features that code both interaural level differences and inter-aural time or phase differences. The latter are calculated on the basis of interaural cross-correlation per one-third octave band. Hence temporal shift and phase shift become strongly related. A probabilistic mapping between angle of incidence of the sound and the strength and uncertainty of the activation of these features is trained for a particular artificial head, using a variety of environmental sounds arriving from a series of well-defined directions. When a sound signal is subsequently received, Bayesian inference is used to estimate a probability distribution over all angles of incidence at any given time and for each frequency.

Focusing of attention to sound coming from a given direction can be implemented as a spectral filtering that mimics the efferent system. The filter signal is further analyzed using the above described monaural feature extractor and source identification. A model that uses the location information for stream segregation has yet to be implemented.

## RESULTS

The models described above were used in several applications; here we present some of the latest results.

### Perceptual model working on simulated sound

One of the observations that is explained by the perception model is the difference between energetic masking and informational masking of unwanted traffic sound by natural sounds that are in general more appreciated, for example broadband fountain sound or high frequency intermittent bird sound. To demonstrate the two varieties of masking, a numerical experiment was set up that consisted of mixing 62 dBA recorded traffic sound with various levels of typical fountain sound on the one hand and typical bird sound on the other. The resulting mix of sounds is fed into the model and the time that the traffic sound could be heard or is expected to be paid attention to is obtained. Figure 1 shows that the broadband fountain sound is more efficient in energetically masking traffic sound at the same $L_{Aeq}$, a result that is quite expected. However, the model also predicts that the bird sound is almost as efficient in drawing attention away from the traffic sound as the fountain sound. The model is thus capable of explaining experimental results such as (De Coensel et al. 2011).

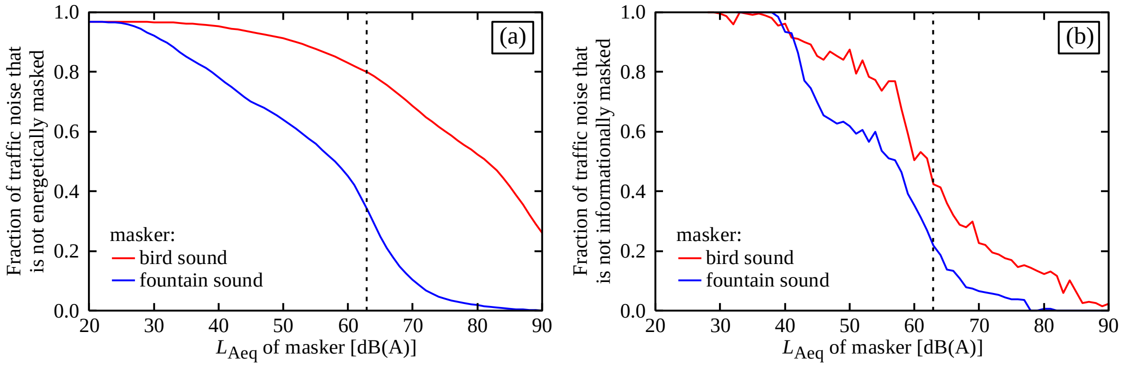


**Figure 1:** Fraction of traffic noise that is not (a) energetically masked, and (b) informationally masked, as a function of the $L_{Aeq}$ of the masker. The dashed line marks the $L_{Aeq}$ of the traffic sound.

## Perceptual model working on recorded sound

One of the advantages of using an automated perception model for analysing the sonic environment is that long-term monitoring can be used to observe long-term changes. A human listener can hardly be motivated for this task. For this purpose, all sounds occurring in an environment during a predefined period of time are first mapped, based on temporal correlated features as explained above. In order to interpret – that is attach meaning – to a sound, a typical sound fragment can be recorded and linked to each point of the map. After this preparatory phase that can be fully automated, the measurement device allows to give statistical information on the frequency of occurrence of sounds, or more importantly, on the auditory importance of each sound in the environment at any desired time of any desired day. Auditory importance is measured as the probability that a sound would attract attention. It is calculated by combining its frequency of occurrence with its saliency. Figure 2 shows the auditory importance of various areas of the map of sounds for a permanent measurement station in the inner city of Ghent for four periods of a particular day. For illustration purposes, the description of the sounds given by a human listener for some of the areas of the maps is added, although in practice listening to the sounds is more instructive.

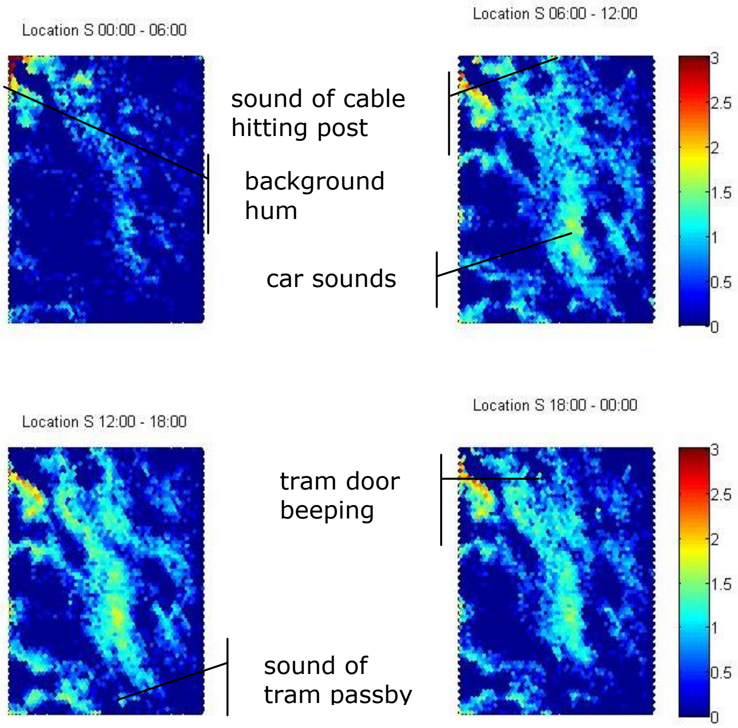


**Figure 2:** Auditory importance of different areas of the map of sounds at different times of the day, red indicating higher importance, blue indicating totally unimportant sounds; samples of aurally identified sounds are indicated.

Figure 3 shows an example of how directional information is extracted from binaural recordings. The latter were made near a street in Lyon; cars are passing by from the left to the right and some talking people can be heard in the time interval between 400 and 600. On the spectrogram the talking cannot be recognized, but when looking at the directional plot, there is some evidence of the existence of a source on the right at high frequencies.

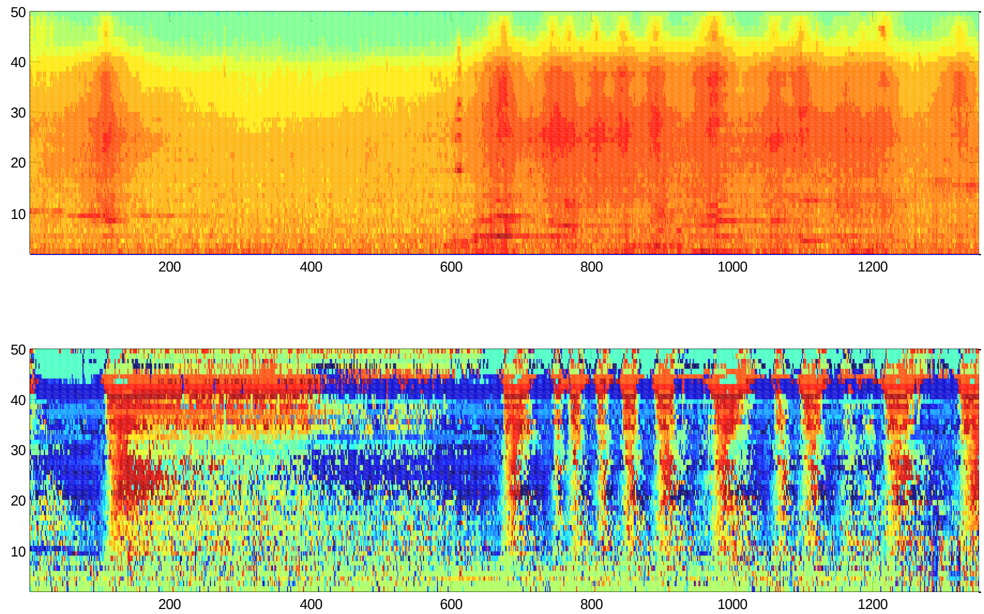


**Figure 3:** Spectrogram (upper) and direction of arrival (lower) obtained from a binaural recording. Blue regions indicate a source at the left, red regions a source at the right. The x-axis shows the time in epochs of 50 msec, the y-axis the frequency in 1/6$^{th}$ octave bands.

## CONCLUSIONS

Modeling the perception of environmental noise may serve several purposes: (1) by making available knowledge on auditory perception explicit, as needed for constructing a model, insight can be gained in plausible underlying mechanisms; (2) a model may explain field observations or lab experiments related to the perception of environmental sounds; (3) a biologically inspired perception model may be used to interpret measurements and extract essential knowledge from microphone signals. In this paper, a set of models that is sufficiently accurate yet computationally feasible has been presented and examples of the above mentioned applications were given. The explicit implementation of attention mechanisms and models to represent binaural hearing gave additional insight in these effects and can be considered good examples of application (1). The emergence of informational masking and differences in perception of road traffic and rail traffic noise provide a possible explanation for at least part of the observed effect (hence (2)). Applications such as the acoustic summary illustrate the applicability of the proposed models as a way of analyzing data from environmental noise monitoring stations (hence (3)).

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# Comparative studies on railway and road traffic noise annoyances and the importance of number of trains

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## INTRODUCTION

It is estimated that about 500,000 people in Sweden are exposed to noise levels from railway traffic exceeding the outdoor guideline value $L_{Aeq,24h}$ = 55 dB, while about three times that number is exposed to noise levels from road traffic. Railway traffic on existing lines is likely to increase in the future due to environmental concerns. The combination of more frequent, heavier and faster trains could therefore increase the number of disturbances. At the same sound level, railway noise is perceived as less annoying than road traffic noise both in terms of general annoyance and sleep disturbances according to dose-response relationships from meta-analyses (Miedema & Oudshoorn 2001). However, with regard to specific effects on communication and other activities that involve listening, all field studies shows that railway noise is more disturbing than road traffic noise (Moehler 1988; Öhrström 1990; Öhrström et al. 2010). Findings in recent years from Japanese (e.g. Morihara et al. 2002) and Korean studies (Lim et al. 2006) show, unlike most European studies, that railway noise is perceived as more annoying than road traffic noise at >$L_{Aeq,24h}$ 55 dB. This applies particularly to the Japanese Shinkansen express trains, as well as conventional trains. Several of the Japanese studies have been done in areas with a very large number of trains (about 500-800 trains per 24 h). The present study aimed to investigate the following questions: How does a large number of trains affect noise annoyance and can the differences between Japanese studies (railway noise more annoying than road traffic noise) and European studies (railway noise less annoying than road traffic noise) in part be due to major differences in the number of trains?

## METHOD

### Design, study area, population, and response rate

The present study formed part of the research project “TVANE” (Train Vibration and Noise Effects; 2006-2010), which investigates in a series of empirical field studies and laboratory experiments how human responses (health and well-being) are affected by (a) road traffic- and railway noise per se, (b) combined exposure to railway noise and vibrations, and (c) high intense railway traffic. Three study sites in Sweden (Töreboda, Falköping, Sollentuna) were selected in areas with railway traffic noise and another two study sites (Kungälv and Borås) were selected in areas with road traffic noise from the major roads E6 and E40. The traffic volume in the road traffic sites varied between 38,500 and 50,000 in Kungälv and between 15,500 and 25,000 in Borås. The two railway sites Töreboda and Falköping are situated at the railway line “Västra Stambanan” between Gothenburg and Stockholm and will henceforth be called “railway area 1”. The number of trains/24h on the two parallel tracks was 124:

78 passenger trains and 46 freight trains (a larger proportion during evening and night, see Table 1). The railway site Sollentuna is one of the residential areas in Sweden that is exposed to the most intense railway traffic. The number of trains per 24h on the four tracks was 481. Most of them are passenger trains, which includes commuter trains (155) and high speed trains (166), the latter travel round trip to Arlanda airport with a speed of about 200 km/h. Only 15 trains are freight trains that run during evening and night (Table 1). This site will henceforth be called “railway area 2”. Table 1 provides details of the number of trains per 24 h and per hour during different periods of the day in the railway areas. During daytime (06-18), 323 trains or one train every two minutes is passing in railway area 2. This is almost seven times as many trains passing compared with railway area 1 (see Table 1).

**Table 1:** Number of trains per 24 hours and per hour during different periods of the day in the two different railway areas.

| | Number of trains/24h | Number of trains 06-18 | Number of trains 18-22 | Number of trains 22-06 |
|---|---|---|---|---|
| Railway area 1 | 124 | 50 | 48 (20 freight trains) | 26 (20 freight trains) |
| | 5.2/hour<br>1 train every 12 min | 4/hour<br>1 train every 14 min | 12/hour<br>1 train every 5 min | 3.2/hour<br>1 train every 18 min |
| Railway area 2 | 481 | 323 | 89 (4 freight trains) | 69 (8 freight trains) |
| | 20/hour<br>1 train every 3 min | 27/hour<br>1 train every 2 min | 22/hour<br>1 train every 3 min | 8.6/hour<br>1 train every 7 min |

Noise calculations using the Nordic Prediction Method (Jonasson & Nielsen 1996) were performed as well as measurements for estimating noise levels ($L_{\text{Aeq,24h}}$, $L_{\text{day}}$, $L_{\text{evening}}$, $L_{\text{night}}$, $L_{\text{AFmax}}$ and $L_{\text{den}}$) at the most exposed side for each residential building. All calculation points were determined at 2 meter above the ground as free field values. The results in the present study is based on data in the $L_{\text{Aeq,24h}}$ range from 45-65 dB, but are presented in relation to both $L_{\text{Aeq,24h}}$ and $L_{\text{den}}$. Table 2 shows the number of respondents per exposure category of $L_{\text{Aeq,24h}}$ and $L_{\text{den}}$ for the three study areas. The study comprised 1,689 participants in total and the overall response rate was 49 %.

Table 3 shows the statistics for sound exposure levels and distance to the main noise source in road traffic and railway areas. As can be seen in Table 3, the mean value of $L_{\text{den}}$ is 2.7 dB higher than $L_{\text{Aeq,24h}}$ (56.0 vs. 53.3 dB) for the road traffic area.

**Table 2:** Number of respondents per sound exposure categories of $L_{\text{Aeq,24h}}$ and $L_{\text{den}}$.

| | Number of respondents per exposure category of $L_{\text{Aeq,24h}}$ | | | | |
|---|---|---|---|---|---|
| | 45-50 dB | 51-55 dB | 56-60 dB | 61-65 dB | Total |
| Road traffic areas | 177 | 120 | 97 | 74 | 468 |
| Railway area 1 (124 trains/24h) | 127 | 266 | 88 | 25 | 506 |
| Railway area 2 (481 trains/24h) | 167 | 280 | 191 | 77 | 715 |
| Total | | | | | 1689 |
| | Number of respondents per exposure category of $L_{\text{den}}$ | | | | |
| | <55 dB | 55-59 dB | 60-64 dB | > 64 dB | Total |
| Road traffic areas | 198 | 130 | 95 | 45 | 468 |
| Railway area 1 (124 trains/24h) | 21 | 210 | 207 | 68 | 506 |
| Railway area 2 (481 trains/24h) | 109 | 319 | 204 | 83 | 715 |
| Total | | | | | 1689 |

**Table 3:** Sound levels from road traffic and railway traffic for the different residences and distance from main road and railway line: Statistics for different exposure metrics.

| Sound exposure metrics: (Mean value, minimum and maximum) | Road traffic areas | Railway area 1 124 trains/24h | Railway area 2 481 trains/24h |
|---|---|---|---|
| $L_{Aeq,24h}$ | 53.3 (44,5 – 65.2) | 52.9 (44.9 – 64.9) | 54.1 (44.6 – 65.6) |
| $L_{den}$ | 56.0 (47.2 – 67.9) | 60.4 (52.3 – 72.3) | 58.8 (49.2 – 70.3) |
| $L_{night}$ | 45.6 (36.7 – 57.4) | 53.6 (45.5 – 65.6) | 51.2 (41.6 – 62.6) |
| $L_{AFmax}$ | 58.5 (44.6 – 83.0) | 71.7 (62.4 – 84.2) | 73.2 (63.0 – 85.0) |
| Distance to major road | 179 (41 – 309) | – | – |
| Distance to railway | – | 206 (35 – 451) | 132 (11 – 343) |

In railway area 1 there is a much larger difference (7.5 dB) between $L_{den}$ and $L_{Aeq,24h}$ due to the distribution of railway traffic over the day (87 % of the freight trains during evening and night) whereas only about 22 % of the road traffic occurred during evening and night. However, the difference is smaller in railway area 2 (4.7 dB) since only 12 freight trains are passing during evening and night.

## Evaluation of effects

Annoyance and other health effects were evaluated using a questionnaire. The format is based on questionnaires previously used in larger epidemiological studies of noise annoyance in Sweden (Öhrström et al. 2006; 2007). The questionnaire was sent to selected persons (aged 18 to 75 years) together with an introductory letter in April 2007 (road and railway area 1) and in April 2008 (railway area 2), which presented the survey as a study on the environment, human health and well-being. Two reminder letters were sent out with 10 day intervals to those who not responded to the questionnaire. The first reminder consisted only of a letter while the other consisted of the reminder letter and a new questionnaire.

General annoyance caused by noise was evaluated with a 5-point category scale (“not at all”, “slightly”, “moderately”, “very”, and “extremely”) and an 11-point numerical scale (0-10 with verbal endpoints “not at all” and “extremely much”) according to the ISO specification of annoyance scales (Technical Specification, International Organization for Standardization 2003). The questions were phrased as follows: “Thinking about the last 12 months or so, when you are here at home, how much does noise from (source) annoy or disturb you”. In the presentation of the results, the “annoyed” category (%A) consists of those who were moderately, very, or extremely annoyed on the five-point category scale. For “highly annoyed” (%HA), categories 8, 9, 10 on the 11-point numerical scale was used as a cut-off criterion, which approximates the criterion used by Miedema and colleagues for converted scales ranging from 0-100 (Miedema & Oudshoorn 2001).

Disturbances of daily activities (e.g. conversation, listen to radio/TV, rest/relaxation, difficulties to keep windows open) were measured both in terms of “How often” (0=“never”, 1=Sometimes, 2=“Often” and “How much” (2=“Slightly”, 3=“Moderately”, 4=“Much”) railway and road traffic noise affected the activity. Summed scales for each question were formed ranging from 0 to 6.

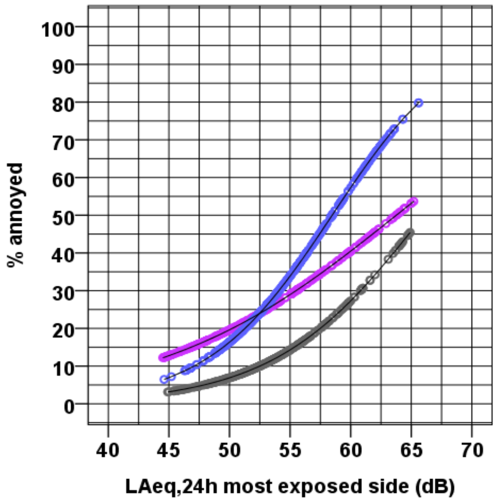
RESULTS

## Background factors

In the three survey areas, the mean age of the respondents ranged between 48 and 51 years of age. More men than women participated in the road traffic area and in railway area 1 (58 and 56 %, respectively), however, the reverse was the case in railway area 2 (56 % were women). A larger proportion of the respondents in railway area 2 (74 %) were married or de facto co-habiting than in the two other areas (56 and 59 %). A majority of the respondents in the three areas were employed or had their own company (range 65-69 %) and the rest had different status such as studying, retirement (early retirement, sickness- or old-age pensioner), unemployed, or were on sick- or parental leave. In railway area 2, a larger proportion (49 %) had a high level of education (≥ 3 years at university) than in the other areas (21 and 24 %). Sensitivity to sound/noise was reported by least respondents in railway area 1 (20 %), whereas in road traffic areas and in railway area 2 the proportion was higher (about 30 %). Except for sensitivity to sound/noise, none of the abovementioned factors together with type of house (detached house or apartment building), what year the house was built, and type of windows (triple-glazed or two-glazed windows/other) were associated with noise annoyance in any of the study areas. More respondents in railway area 2 than in railway area 1 lived at a shorter distance to the railway and also reported disturbance due to vibrations and aircraft noise. This was controlled for in the analyses by excluding them and comparing the results for the whole sample. No significant differences were found.

## General noise annoyance from railway and road traffic noise in relation to sound levels in $L_{Aeq,24h}$ and $L_{den}$

The relation between sound levels ($L_{Aeq,24h}$, $L_{den}$) from road traffic and railway traffic and general noise annoyance (% annoyed) was analyzed with binary logistic regression, see Figure 1 and Table 4. Separate analyses were done for each of the three study areas. The response curves are presented without taking potential moderation factors into account (e.g. sensitivity to sound/noise, access to a “quiet” side or nearby green areas).



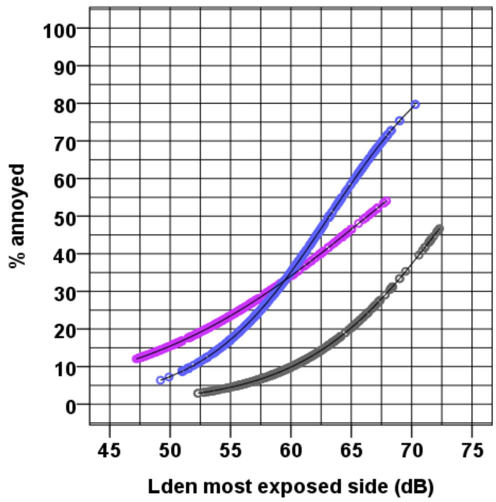




**Figure 1:** Estimated dose-response relation between sound levels in $L_{Aeq,24h}$ (left) and $L_{den}$ (right) and %A by road traffic noise (purple curve) and railway noise (railway area 1 with 124 trains/24h = grey curve and railway area 2 with 481 trains/24h = blue curve)

The estimated %A in relation to $L_{Aeq,24h}$ (left) in road traffic areas is higher than in railway area 1, a difference of 5 to 15 % units depending on sound level (Table 4). The difference in annoyance is smallest at the highest sound levels. The %A in railway area 2 is higher than in road traffic areas when noise levels are above $L_{Aeq,24h}$ 55 dB. The difference is 27 % units at 65 dB (77 vs. 50 %, for railway area 2 and road traffic areas, respectively). The largest difference in annoyance is seen between the two railway areas ranging from 10 to 32 % units. The estimated %A in relation to $L_{den}$ (right) is consistently over 20 % units higher in the road traffic areas than in railway area 1. Noise annoyance is higher in railway area 2 than in road traffic areas when $L_{den}$ is > 60 dB. The difference between the two railway areas is very large ranging from 12 to 43 % units. For road traffic areas and railway area 2, annoyance ratings were higher than predicted by standard curves presented in the EU position paper on dose response relationships between transportation noise and annoyance (Miedema & Oudshoorn 2001; EU 2002), particular for railway area 2 (see ratings in red within brackets).

**Table 4:** Estimated proportion of noise annoyed respondents to road traffic and railway noise for different noise exposure levels in $L_{Aeq,24h}$ and $L_{den}$.

| | Noise exposure levels in $L_{Aeq,24h}$ | | | |
|---|---|---|---|---|
| | 50 dB | 55 dB | 60 dB | 65 dB |
| Road traffic areas | 20 | 30 | 40 | 50 |
| Railway area 1 (124 trains/24h) | 6 | 15 | 27 | 45 |
| *Difference road – railway area 1* | *+14* | *+15* | *+13* | *+5* |
| Railway area 2 (481 trains/24h) | 16 | 35 | 56 | 77 |
| *Difference road – railway area 2* | *+4* | *-5* | *-16* | *-27* |
| *Difference railway area 2 – railway area 1* | *+10* | *+20* | *+29* | *+32* |
| | Noise exposure levels in $L_{den}$ | | | |
| | 55 dB | 60 dB | 65 dB | 70 dB |
| Road traffic areas | 25 (18) | 35 (26) | 46 (35) | *60 (47) |
| Railway area 1 (124 trains/24h) | 5 (10) | 10 (15) | 20 (23) | 37 (34) |
| *Difference road – railway area 1* | *+20* | *+25* | *+26* | *+23* |
| Railway area 2 (481 trains/24h) | 17 (10) | 36 (15) | 57 (23) | 80 (34) |
| *Difference road – railway area 2* | *+8* | *-1* | *-11* | *-20* |
| *Difference railway area 1 – railway area 2* | *+12* | *+26* | *+37* | *+43* |

* No data exist.

## General noise annoyance in relation to the orientation of balcony/patio and bedroom window

The relation between sound levels in $L_{den}$ from road traffic and railway traffic and %HA was analyzed with binary logistic regression and also taken into account the influence of the orientation of balcony/patio and bedroom window (towards noise source or towards backyard/small road), see Figures 2 and 3, respectively. Separate analyzes were done for each of the three study areas. The dose-response curves in Figure 2 for all subjects (left) show that the estimated %HA curves in relation to $L_{den}$ in road traffic areas and railway area 2 are approximately the same and they are also higher than in railway area 1.

Having balcony/patio oriented towards the noise source increased the odds of being highly annoyed in all three study areas, but mostly in road traffic areas and railway area 2 (road traffic areas, OR=5.29, 95% CI=2.87-9.75; railway area 1, OR=4.49, 95% CI=1.61-12.49; and railway area 2, OR=5.25, 95% CI=3.25-8.49). For road traffic areas and railway area 2, orientation of balcony/patio towards noise source predicted the percentage of highly annoyed residents to increase from about 23 % at $L_{den}$ 55 dB to about 48 % at 65 dB (Figure 2, middle). For railway area 1, these numbers ranged between about 5 to 17 %. The difference between %HA among those having the balcony/patio oriented towards the noise source or not is much greater in road traffic areas and in railway area 2 than it is in railway area 1 (see Figure 2 middle and right).

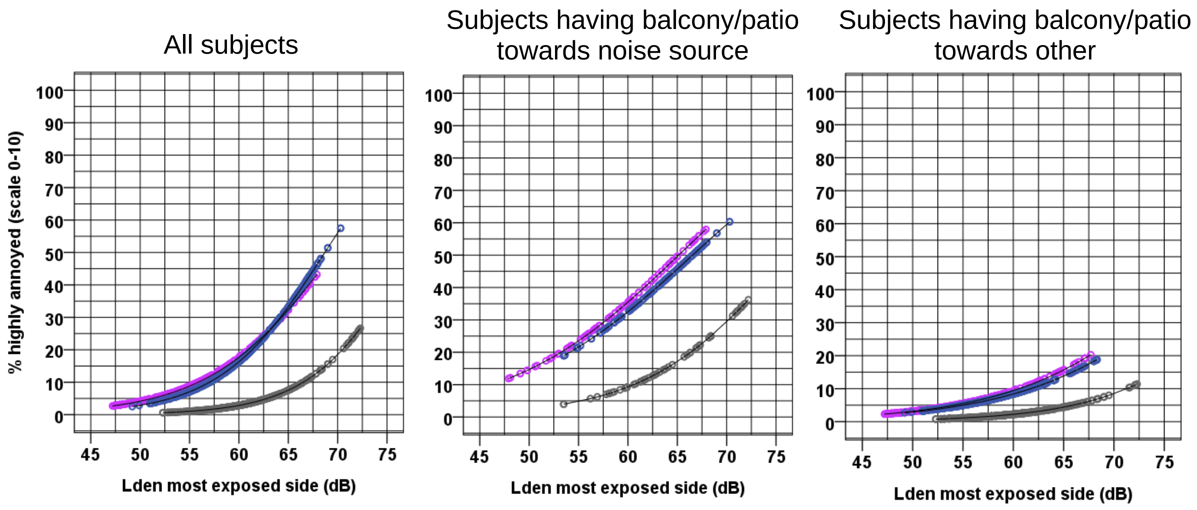



**Figure 2:** Estimated dose-response relation between $L_{den}$ and %HA by road traffic and railway noise (left=all cases included) and in relation to balcony/patio oriented towards noise source (middle) and towards other (right) for the three survey areas road traffic noise (purple curve) and railway noise (railway area 1 with 124 trains/24h = grey curve) and railway area 2 with 481 trains/24h = blue curve)

Having bedroom window oriented towards the noise source increased the odds of being highly annoyed mostly in road traffic areas (OR=5.23, 95% CI=2.85-9.59), but also in railway area 2 (OR=2.24, 95% CI=1.38-3.65). For railway area 1, the orientation of bedroom window has no significant effect on %HA ($p$>0.05). The dose-response curves in Figure 3 (middle) show that orientation of bedroom window towards the noise source in road traffic areas give larger estimated proportions of highly noise annoyed respondents at any given $L_{den}$ level than in the two railway areas.

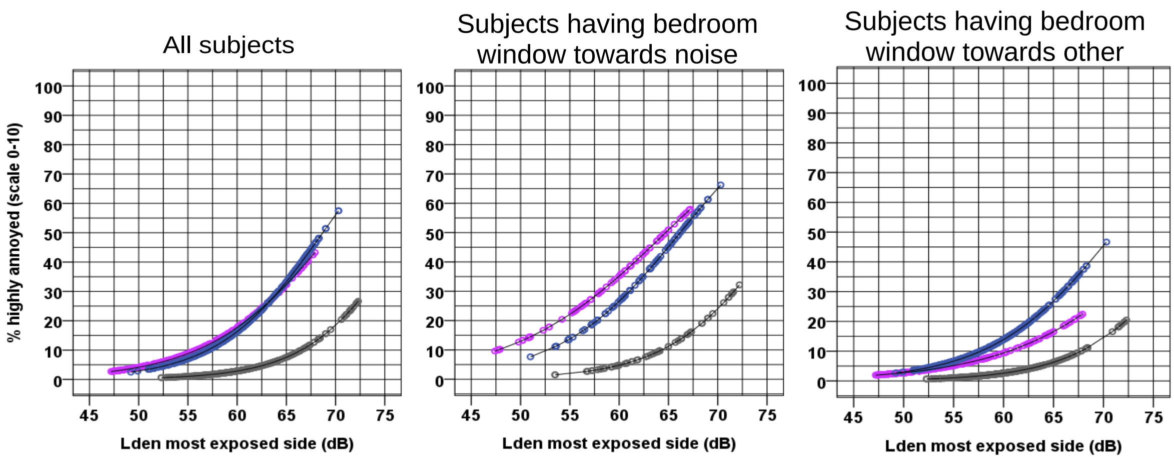



**Figure 3:** Estimated dose-response relation between $L_{den}$ and %HA by road traffic and railway noise (left=all cases included) and in relation to bedroom window oriented towards noise source (middle) and towards other (right) for the three survey areas road traffic noise (purple curve) and railway noise (railway area 1 with 124 trains/24h = grey curve) and railway area 2 with 481 trains/24h = blue curve)

Thus, in the case of road traffic noise, the difference between percentages of highly annoyed among those having bedroom window oriented towards the noise source or not is much larger than it is in the case of the two railway areas, especially for railway area 1. For road traffic areas, the orientation of the bedroom window is just as important for general annoyance as the orientation of the balcony/patio.

**Associations between general annoyance and disturbances of daily activities indoors and outdoors**

Table 5 shows correlations (Spearman's $r_S$) between general annoyance (0-10 scale) and various noise disturbed daily activities indoors with windows closed and open and outdoors in the three study areas. As can be seen, both railway areas obtained higher correlations between general annoyance and activity disturbances that involved communication (listen to radio/TV, conversation) in all three situations than road traffic areas. Although the association between rest/relaxation and general annoyance were stronger in road traffic areas than in railway area 1, the strongest correlations were seen for railway area 2.

**Table 5:** Correlations ($r_S$) between general noise annoyance at home (0-10 scale) and disturbances of daily activities (range 0-6) in the three different study areas.

| Activity disturbances | Road traffic areas | Railway area 1<br>124 trains/24h | Railway area 2<br>481 trains/24h |
|---|---|---|---|
| | *Indoors with windows closed* | | |
| Rest/relaxation | 0.61 | 0.45 | 0.66 |
| Listen to radio/TV | 0.34 | 0.44 | 0.51 |
| Conversation | 0.27 | 0.39 | 0.53 |
| | *Indoors with windows open* | | |
| Rest/relaxation | 0.64 | 0.57 | 0.75 |
| Listen to radio/TV | 0.49 | 0.57 | 0.71 |
| Conversation | 0.46 | 0.53 | 0.72 |
| | *Outdoors* | | |
| Rest/relaxation | 0.67 | 0.55 | 0.78 |
| Conversation | 0.52 | 0.52 | 0.80 |

## SUMMARY AND CONCLUSIONS

The overall results in this paper suggest that road traffic noise is more annoying than railway noise at the same noise level of $L_{Aeq,24h}$ or $L_{den}$, which is consistent with most previous international and European studies (e.g. Miedema & Oudshoorn 2001; EU 2002; Öhrström & Skånberg 2006). However, the findings also suggest that the number of trains per 24h, and not just the noise levels, is relevant for how annoying railway noise is perceived. As the railway traffic is very intense, 481 trains/24h or about one train passing every three minutes, railway traffic generate higher or similar general noise annoyance as road traffic, depending on exposure metric and degree of annoyance. This is to some extent in agreement with more recent studies conducted in Japan and Korea (e.g. Morihara et al. 2002; Lim et al. 2006). Furthermore, intense railway traffic caused significantly and substantially greater annoyance at the same noise levels than moderately intense railway traffic (124 trains/24h or about 5 trains/hour). This contradicts findings by Moehler and Greven (2005), who found no effect of more annoyance with higher number of passing trains.

Of great importance for general annoyance was the position of balcony/patio and bedroom windows in relation to noise sources. For respondents exposed to road traffic noise, the orientation of the bedroom window seems to be as important for general annoyance as the orientation of the balcony/patio. The results from the railway areas suggest that it may be more important that balcony/patio is not oriented towards the railway than that bedroom window is oriented towards the shielded side. Particularly in situations with intense railway traffic, as in railway area 2.

Several factors have been proposed to explain why railway noise is less annoying then road traffic noise. These include differences in noise characteristics (railway noise more regular and predictable) as well as factors related to perceptions and attitudes towards these two noise sources (e.g. Fields & Walker 1982). Other potential influencing factors (Lim et al. 2006) in this study (distance to railway, exposure to vibrations and aircraft noise) were controlled for. Since there were no other obvious differences in background or environmental factors between road traffic and railway areas and between railway area 1 and 2 in the present study, we find it reasonable to assume that when the number of trains per 24h is high, it will be similar to noise exposure from road traffic. That is, the railway noise will be perceived as more continuous and less intermittent with fewer “quiet” periods, as previously suggested (Fields & Walker 1982). This is supported by the fact that the slope of the HA curves for high intense railway traffic is comparable with the slope of the HA curves for road traffic areas. Moreover, the dominating effect of road traffic noise is disturbance of rest/relaxation (see also Öhrström et al. 2010) and the results show that railway noise has a similar effect in the area with high intense railway traffic.

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# The types of human response to changes in noise exposure

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## INTRODUCTION

It has been widely recognized that annoyance is one of the most common effect of environmental noise. Noise annoyance consists of several aspects including immediate behavioral effects such as disturbance and evaluative aspects such as nuisance or unpleasantness (Guski et al. 1999). Exposure-response data show that annoyance generally increases with noise levels (Fidell 2003; Miedema &Vos 1998). Due to environmental, social and personal factors (Job 1988), large heterogeneity has been observed in these curves and the actual noise level has been found to explain only 10 to 25 per cent of an individual reaction to noise (Job 1996). In addition, annoyance may not be stable over time; some studies found that annoyance due a given aircraft noise level has been increasing over time(Babisch et al. 2009; Brink et al. 2008; Guski 2004; Masurier et al. 2007).

In the literature on human response to increased (or reduced) noise exposures, annoyance is generally considered as the main indicator of the subjective response. Vallet (1996) however found that a minimum of 6 dBA change is required in noise level before annoyance changes. Moreoverannoyance reactions for those exposed to changes in noise levels might differ from those predicted by the steady-state exposure-response curves – i.e. for people with (presumed) reasonably constant noise exposure levels (for review see Brown & van Kamp 2009a, b). It is therefore questioned whether the change in annoyance is the best indicator of human reactions to changed noise exposure.

The main aim of this paper is to review the evidence on human reactions to changes in environmental noise exposures in order to present alternative reaction measures other than annoyance. Factors that influence annoyance ratings in changed noise conditions are further discussed. The implications of the findings may help guide policy decisions when impact assessment of proposed changes takes place.

## METHODS

### Study search

Web of Science, PubMed and Embase were searched from 1980 to March 2011 to indentify relevant articles written in English. In addition, the reference list from relevant original research and review articles and conference proceedings (Internoise 2001-02, 2004-05, 2007-‘08, ‘10) were reviewed. A Google hand search was also performed for grey literature. The search terms included noise, change, reaction, perception, response, annoyance, human community, individual, air, traffic, and rail.

### Study selection

The following inclusion criteria were applied: (1) the study measured the change in environmental noise (community, traffic, road, aircraft and railway) exposure, (2) the change in noise level was due to (i) a new (or eliminated) source or change in intensity of the source (e.g. traffic flow change, road bypass construction, change in runway configuration), or (ii) some intervention (e.g. noise barrier, insulation),(3) it provided qualitative/quantitative information on reaction or response or perception due to changes in noise conditions, (4) the study quantified and/or described the relationship between changes in environmentalnoiseexposure and community or individual reaction/response/perception/use of living environment, (5) the response was measured in the same population before and after the change in noise levels, (6) the investigation was carried out on humans, and (7) the paper was written in English. Papers that contained no original data were not considered in this review. The selection of studies has conducted in two steps: first the title and abstracts of all records were checked; then the potential relevant papers were retrieved, read in full by the two reviewers and assessed against the inclusion criteria.

### Data extraction and quality assessment

The studies that satisfied the inclusion criteria were grouped into four categoriesas types of measures of response: (1) changes in annoyance, (2) activity disturbance, (3) physiological and psycho-social well being, and (4) use of living environment. Since our main interest was to review different responses other than annoyance, it was decided that data would be extracted only from studies in group (2-4). Those studies investigating changes in annoyance (Group 1) were not extracted, but screened to identify factors that influence annoyance ratings in changed noise conditions. The two authors performed the data extraction independently according to a standardized format. Each study was summarized in a tabular form by extracting information on study population, study design, noise source, noise exposure, direction of change in noise exposure, reason for change in noise exposure, measures of response, method of measure the response, confounding factors and conclusion. Disagreements between the reviewers were resolved by consensus. The study quality was judgedusing guidelines of the Cochrane Collaboration(http://www.cochrane-handbook.org/).

## RESULTS

The database literature searchyielded 439 records (Web of Science 236, Pubmed 69, Embase 134). Based on their abstracts 82 records found to be possibly relevant (Web of Science 16, Pubmed 4, Embase 6, Internoise proceedings 11, reference list screening 41, Google search 9). After reading the full papers, 29 records were excluded because the studies did not measure the changes in noise exposure (14), the reason of the change in noise exposure was different to that it was described in the inclusion criteria (1), the response was not measured for the same population (3), the paper was not in English (3), or the paper contained no original research (8 review papers). Seven publications were about the same two experiments. We could not retrieve four papers.

### Reaction other than annoyance in changed noise conditions

Table 1 presents some results on different measures of reactions in changed noise conditions. The full tabular format summarizing the studies will be shown and the findings will be discussed at the conference in more detail.

**Table 1:** Studies that measured reactions to changed noise conditions other than annoyance

| Reference | Noise source | Noise exposure[1] | Direction of change in noise exposure | Reason of change in noise exposure | Measures of response |
|---|---|---|---|---|---|
| Amundsen 2007 | road traffic | C | reduction | Insulation, noise barrier | annoyance and sleep disturbance |
| Eberhardt & Akselsson 1983 | road traffic | M | reduction | insulation | sleep disturbance |
| Fidell et al. 2000 | aircraft | M | reduction and increment | airport relo-cation | sleep disturbance |
| Fidell et al. 2002 | aircraft | C | increment | new runway opening | annoyance, sleep disturbance and speech interference |
| Gomez-Jacinto & Morel-Toranzo 1999 | road traffic | M | reduction | insulation | arousal, disturbance of daily life, perceivedunpleasantness |
| Hume et al. 2004 | aircraft | C | increment in air traffic movements | new runway opening | number and pattern of complaint |
| Krog et al. 2004, 2010 | aircraft | M | reduction and increment | airport relo-cation | changes in use of outdoor recreational area |
| Moehler et al. 1997 | railway | M | reduction | rail-grinding | annoyance, disturbance in conversation, relaxation, con-versation outdoors, disturb-ance while going to sleep |
| Nilsson & Ber-glund 2006 | road traffic | M and C | reduction | noise barrier erection | annoyance, interference with speech communication and sleep disturbance |
| Ohrstrom & Bjorkman 1983 | traffic | M | reduction | insulation | sleep disturbance |
| Ohrstrom 2004 | road traffic | M and C | reduction | reduction in traffic load | annoyance, activity disturb-ance, sleep and well-being, use of living environment |
| Stansfeld et al. 2009 | road traffic | M | reduction | introduction of a bypass | annoyance, quality of life, mental disorder |

[1]M-measured, C-calculated

12 studies investigated reactions other than annoyance to changed noise conditions. The study design was a before-after type (with control group in some cases). Most of these studies measured sleep disturbance before and after changes in noise exposure were introduced. A structural equation model used by Gómez-Jacinto & Moral-Toranzo (1999) indicated that arousal and disturbance due to noise were good indicators of the perceived noise.

### Factors influencing annoyance in changed noise situations

Due to the large number of factors influencing noise exposure-effect relationship, it is difficult to disentangle the effects of noise exposure on human reaction from the effect of other individual and situational factors. Moreover annoyance depends on several non-acoustical factors such as noise sensitivity and fear of noise source (Miedema & Vos 1999), attitudes towards the noise source or anticipation of the change (Brown & van Kamp 2005) or having access to the quiet side of the dwelling (Ohrstrom et al. 2006).

Little is known about factors that affecting on annoyance in a changed noise situation. According to Brown & van Kamp (2009a) one of the explanations for a changed effect in response is a change in variables that modify the exposure-response relationship before and after the change. This explanation also suggests that modifying variables become more positive when noise exposure decreases and more negative when noise exposure increases. Therefore effect modifiers may be very different and have different effect on annoyance in before and after situations. In a study on residents' reactions to the opening of a new railway, Au et al. (2005) for example found that before the opening of a new railway line, people's annoyance levels were determined by their perceived noisiness and their noise sensitivity. However, after the opening of the railway, attitude towards railway became an annoyance predictor.

In the Norway airport relocation study Krog & Engdahl (2004) found that the **situational variable** (if the response was measured before or after the relocation of the airport) was more influential on changes in annoyance than the actual noise exposure itself. However, the authors noted that the situation variable represented a different kind of change (i.e. decreased noise exposure when airport was moved and an increased noise exposure at the place where the airport was relocated). Thus the effect size of the situation may also depend on the direction of change, different expectations to sound quality and different recreational areas. It was also suggested that the time span between the relocation and the time of the after study should be taken into account.

In the same study it was found that variables that predicted annoyance with aircraft noise before the change did not predict transition from use to non-use of recreational areas after the change (Krog 2010). The probability of a transition in both noise changing situations was positively influenced only by the level of **prior experience** with the area. Kastka et al. (1995) also found that residents with experience of the 'before situation' are much more influenced by the 'before experience' even after 12 years of a noise barrier erection. The results suggest that annoyance might be influenced by previous experience or people may **adapt** to the new circumstances and judge a noise situation based on this experience; the more experienced the respondent is in the area the more likely to accept and adapt to the new situation. However Egan et al. (2003) reviewed studies on adaptation and disturbance after opening of major urban roads and foundno evidence of adaptation. A similar conclusion has been drawn by Weinstein (1982); no adaptation was observed following the opening of a new major road over a period of 4 to 16 months. Although Brown (1987) found no evidence for adaptation to increased road traffic noise between 7 and 19 months, he noted that adaptation could have occurred shortly after the change in traffic noise exposure. Findings are related to relatively long adaptations and annoyance is not studied immediately following the change (Fields 1993).

**Temporal and spatial factors** have been found to be important annoyance modifiers in changed noise conditions. A permanent change in noise exposure islikely to produce different reactions compared with temporary changes (Fields et al. 2000). Guski (2005) suggested that not only the type of change in noise exposure but the time history of the change (i.e. step change or gradual change) can have an effect on the reaction. Length of residency was found to be related to percentage highly annoyed (%HA) 18 months after opening a new railway; community annoyance changed among those who lived in the area before the opening and no change was observed among newcomers (Kastka et al. 1995).

Significant difference in the number of complaints per month, day-of-the-week and hour-of-the-day were found before and after opening a new runway (Hume et al. 2004). *Time of the day* dependent annoyance reactions to changed noise conditions were also observed elsewhere (Brink et al. 2008). Moreover, s*easonal effects* might distort comparisons of annoyance prevalence rates depending on the time of the interview (Fields et al. 2000).

Griffiths & Raw (1986) suggested that confounding by *dwelling orientation* can also be important in increased noise situations.When the *distance from the source* was taken into account in annoyance reactions after erecting a noise barrier, Mital & Ramakrishnan (1997) showed that only those residents who lived close to the barrier were satisfied with the noise installation. Similar conclusion about distance dependent annoyance reaction has also been drawn (Nilsson & Berglund 2006; Kastka et al. 1995). In addition, annoyance reactions varied when *indoor or outdoor* annoyance was evaluated (Nilsson & Berglund 2006).This may also be related to *window opening habits* (Ohrstrom 2004).

Since several studies on traffic volume change (Griffiths & Raw 1986, 1989) showed an excessive effect on annoyance; this was not commonly found in intervention studies; thus *different noise reduction methods* (i.e. changes in noise level and noise intervention) may not have the same effect on annoyance (Griffiths & Raw 1986; Langdon & Griffiths 1982). This might be related to the visibility of the source.

Increased **media cover** can invoke negative reactions, for example, opening of a new railway (Hume et al. 2004). Similar observations have been found in a railway extension study; both information bias and the frequency of using the new line significantly affected the respondents' annoyance reactions, but no interaction was observed between the two factors investigated (Chan & Lam 2008; Lam & Au 2008; Lam & Chan 2007). The study population was divided into two groups. An information sheet describing noise mitigation measures was provided both groups prior to the extension. However the content of the sheet was different: Group A received information about noise mitigation measures that had already been implemented, while Group B received information about possible reduction methods that had not yet been implemented. After the opening of the new railway, Group A found to be significantly more satisfied with the mitigation measures than Group B. They also noted that the effect of the two factors remained significant after a month. Additionally people who used the line more frequently were more tolerant to the noise impact of the new line.

People are more annoyed if they believe that noise could be prevented by authorities (Schreckenberg et al. 2001). It was shown that **mistrust** in the intentions of planners before a new railway was built had a great effect on annoyance; those who mistrusted the planners had more negative expectations with regard their future annoyance or future disturbance. Thus the greater the mistrustthe more the expected future disturbance exceeds the actual disturbance. In addition, the mistrust in the before situation also correlates with the later actual annoyance after the extension of the railway.

Studies that used retrospective assessment may suffer frombias that can be explained by a **response bias** model. Brown (1987) found that following an increase in noise levels, retrospective assessments of annoyance with previous low noise conditions are much lower than were assessments of the same condition made before the change occurred. In contrast, following a decrease in noise levels, retrospective annoyances of annoyance with previous high noise conditions are much higher than were assessments of the same condition made before the change occurred (Brown et al. 1985). It was also speculated the people chronically exposed to low levels of noise may use different frame of reference for annoyance scales to people who are constantly exposed to high levels of noise (Brown 1987).

## CONCLUSION

Previous studies suggest that annoyance *per se* is might not be a precise estimate of human reactions in changed noise situations. It is therefore important to test other variables that can be used for this purpose. Very few studieshave been identified that address reaction measures other than annoyance in changed noise situations. The heterogeneity of study designs and outcome measures (e.g. sleep disturbance, activity disturbance, well being, etc) makes it difficult to draw any firm conclusions. The 'alternative' measures of reactions presented in this review should be further evaluated in prospective studies. Their reliability should be compared with annoyance measures as well their sensitivity to bias.

Annoyance measures are generally used both in steady state and changing noise exposure evaluation studies. However the mechanism of how residents judge their level of annoyance in response to exposure changes is not fully understood. It has been shown that annoyance is modified by several acoustical and non-acoustical factors. Guski (1999) distinguished between social and personal co-determinants of annoyance. Attitudes and expectations belong to the category of social co-determinants, while noise sensitivity or coping are stable personal factors. Social factors play a major role in predicting noise annoyance between the announcement and implementation of changes in noise exposure (Schreckenberg & Meis 2007). Thus minimizingnoise annoyance can be achieved by modifying the social co-determinants. Providing sufficient information about planned changes, increasing the trust in authorities, encouraging public engagement and discussion as well as motivating the public to use the new infrastructure all contribute to the reduction of annoyance.

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# Aircraft noise indexes - recent developments and current applications*

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## ABSTRACT

In this paper, we briefly report about recent developments and current applications of aircraft noise indexes at the airports of Zurich where, since a few years, the ZFI (Zürcher Fluglärm Index) is in force, and Frankfurt with its FFI/FNI (Frankfurter Fluglärm Index).

## INTRODUCTION

Aircraft noise indexes are integral noise monitoring instruments that express the overall effects of aircraft noise, created by a particular airport as one or two rating figures. By accounting for the most important effect measures (such as annoyance or awakening reactions) and by weighting these measures according to the population density at each grid point within a defined geographic perimeter, noise effect indexes provide residents and authorities with an integral picture of the total noise effect.

Usually, noise protection and abatement concepts are based on predicting annoyance from time-integrated levels of acoustic energy (such as the $L_{eq}$, $L_{dn}$, or $L_{den}$) and setting exposure limits below which it is generally assumed that the well-being of the majority of the population is not seriously affected. In contrast to roads or railway lines, airports can more easily be understood as clearly circumscribable noise emitting installations, similar to industry complexes. The air traffic they 'produce' is responsible for the aircraft noise exposure of the population living in the vicinity of the airport. The overall noise effect from one particular airport can thus be expressed in a single figure, e.g. as the number of people living within a particular exposure contour. In this paper, we propose a more elaborate and effect-oriented approach to aircraft noise assessment with – as they will be called – noise effect indexes. Noise effect indexes are an effective measure to evaluate different operation modes of an airport as a whole, or to survey the effectiveness of previously installed noise abatement measures as well as to monitor changes of the distribution of the noise burden around an airport's vicinity. By expressing noise effect as number of people affected, they can also be used as a basis for (financial) compensation schemes between different municipalities.

* Parts of this paper have appeared in Brink et al. (2010)

The development of noise effect indexes has been fostered by the increasing public interest in aircraft noise assessment and related legal issues as well as increasing scepticism towards established forms of noise legislation. In particular, the airport expansion plans in Frankfurt and the increasing political pressure in Zurich in the last decade has prompted plans by the local governments and the airport authorities to develop noise effect indexes to measure the overall effect of aircraft noise on the population both as regards the current state as well as the situation when new flight regimes will eventually be installed. In this paper, we report on the basic features of noise effect indexes and review preliminary experiences with such indexes as they are applied in Zurich and Frankfurt.

## EXPRESSING NOISE IMPACT AS NUMBER OF PEOPLE AFFECTED

The total noise impact an airport generates is depending on the operating plan enforced, type and number of airplanes, flight routing, time of day (or night) and many other factors. It is in the nature of things that such factors are oftentimes subject to public debate. Governments or airport authorities are thus prone to be impelled to evaluate the 'best' (in their view) possible mode of operation of an airport and to substantiate their decisions. Assuming that the 'best' possible mode of operation would be a mode which affects as few people as possible – potentially even at the cost of a few – the best descriptor of 'total noise impact' would be a computable figure expressing the total number of people affected by a particular level of effect. Noise effect indexes exactly accomplish this task. In their basic form they are calculable monitoring values that are capable of expressing total current noise impact or predicting unwanted noise effects of current and future flight scenarios (e.g. after changes of flight routes) of a single airport.

The idea of expressing noise impact instead of using acoustic measures in the form of number of people (affected) is not revolutionary. In the literature, it has been formulated as early as 1993 (Hede 1993). The most often adopted concept to describe total noise impact of such installations as airports is counting the number of residents derived from census population figures within a particular noise contour (often at the levels of exposure limits set out in the law). The idea of counting people within exposure contours on one hand ignores people that are affected below the exposure that defines the contour in question, and on the other – more importantly – does not differentiate enough between different exposure classes and therefore, different magnitudes of effect. Consider the following example: The probability to be "highly annoyed" at a particular exposure level is a continuous function of the exposure level, hence the best estimate of the number of people that are in fact "highly annoyed" at a particular location is the multiplication of the number of residents with the probability in question. To obtain the grand total of the number of people affected by a particular effect, the individual results of all the distinct locations (grid points, receiver points) within the relevant area that is covered by the index must be summed up. Practically, the calculation of a noise effect index therefore requires a grid of receiver points, e.g. using a one-hectare resolution and a set of criteria which define the set of receiver points that are part of the index.

In contrast to integrated *noise exposure metrics* (e.g. $L_{Aeq}$, $L_{dn}$), noise effect indexes can be regarded as integrated *effect metrics*. While exposure metrics are insensitive towards the presence of people, integrated effect metrics express the overall noise effect an airport exerts on the population around it. The basic idea behind expressing noise in terms of people is that policy makers can quickly grasp the overall noise effect of a facility in a single number which is self-explanatory and does e.g. not require any knowledge of acoustic measures. The outcome of noise, e.g. the number of people highly annoyed, is more easily comprehensible than abstract decibel values. This is quite practical for policy-makers planning flight routes and residential settlement patterns in noise-impacted areas.

The calculation of an index I for a set of receiver points i for a particular effect category e (e.g. for %HA, %A etc.) takes the general form

$$I_e = \sum_i N_{pop,i} \times f_e(L_i) \quad (1)$$

with:

$N_{pop,i}$ Number of residents at receiver point i
$f_e(L_i)$ Function of the exposure L at receiver point i for the effect category e

If e.g. the effect-category specific exposure-effect function yields the probability of high annoyance ($P_{HA}$), a value between 0 and 1, then the index I equals the best statistical estimate of the number of highly annoyed people within the area the index is calculated.

It is of course also possible to express other effect measures than number of people such as e.g. total number of aircraft noise induced awakening reactions (in that case, the effect-category specific exposure-effect function can theoretically take a real value between 0 and infinity). The inclusion of single event-related awakening probability within a noise effects index does require the computation of the distribution of the frequency of single event metrics (such as $L_{max}$) within the night time. The average number of awakenings at a particular receiver point for a single person $N_{AWR,i}$ (2a), and the total number for the whole index $I_{AWR}$ (2b) within a chosen observation period, is then given by

$$N_{AWR_i} = \sum_{j=1}^{n} f(Lmax_{ij}) \quad (2a)$$

$$I_{AWR} = \sum_i N_{pop_i} \times N_{AWR_i} \quad (2b)$$

with:

i,j Indexes for receiver points i and noise events j
n Number of noise events within the observation period
$Lmax_{ij}$ Maximum sound pressure level produced by event j at receiver point i

The question of *severity* of a particular number of aircraft noise induced awakenings in terms of possible health impacts is a matter of ongoing discussion in the scientific community. However, to the general public, awakening reactions are an easily explainable and plausible indicator for night noise effects.

## OVERVIEW OF THE AIRCRAFT NOISE INDEXES USED AT ZURICH AND FRANKFURT AIRPORT

This section briefly reviews the "Zurich Aircraft Noise Index" (ZFI) and the "Frankfurt Aircraft Noise Index" (FFI). Both ZFI and FFI are officially released by governmental authorities. Although the authors of this article have – to different degrees – been involved in either the development or evaluation of these indexes, they claim no authorship and hence no responsibility for any scientific or practical shortcomings these indexes may be burdened with. In the next sections, the historical background, aim and scope, and the current application of the ZFI and FFI index are described.

### Historical perspective

The first (published) ideas of adopting an integral approach towards noise rating by promoting the assessment of total noise impact of a given source according to population density, appeared in the early nineties in Australia. Hede (1993) proposed to use impact descriptors instead of exposure measures for environmental assessment purposes and in 2000, Southgate and colleagues proposed the Person-Events Index (PEI) and the Average Individual Exposure Index (AIE) to assess the total noise load of airports (Department of Transport and Regional Services 2000). In Norway, authorities have introduced a noise index called SPI (Norwegian "støyplage indeks"). This indicator is based on the total noise dose from separate sources, the number of residents that are exposed to these doses, and dose-response relationships that describe the annoying properties of these sources (Gjestland et al 2002). The environmental authorities of Norway have decided to use this index to monitor progress towards a noise reduction target that has been passed in the parliament in 1999. A suggestion for incorporating the health effects from all noise sources in a population-density weighted joint index have also been formulated in France recently (Baulac et al. 2010).

Within the past years, the local governments of the Canton of Zurich in Switzerland and later the State of Hessen in Germany have independently commissioned noise effects researchers and acousticians to make propositions for an integral noise impact assessment method for aircraft noise at their airports which were later called "Zürcher Fluglärm-Index" (ZFI) and "Frankfurter Fluglärm Index" (FFI), respectively.

### Zurich Aircraft Noise Index (ZFI)

As a consequence of the restrictions pertaining to the usage of southern German airspace, which were put into effect by the German government as of October 19th 2001, the airport authorities in Zurich were forced to adopt a quite complex flight regime for inbound flights which burdens different communities at different times of day. In the wake of the emerging public pressure to tackle the noise problems at Zurich Airport, the government of the canton of Zurich decided to establish an advanced aircraft noise effects monitoring method in order to keep a close watch on how the noise situation around the airport develops. The monitoring method should be able to calculate the total aircraft noise impact on the population around Zurich airport, and express it in a meaningful way. Furthermore, it should also allow effect-oriented assessments of the noise single communities are burdened with in order to compare and evaluate different operating plans in terms of the overall noise effect they produce. The method's predictions should also be accurate enough so that active noise mitigation measures that were implemented, such as changes of flight routes, or changes of the fleet, were reflected in the result. Based on a preliminary suggestion – made within the scope of a feasibility study (Hofmann 2006) – an assessment procedure called "Zürcher Fluglärm Index" (ZFI) emerged in 2006 and was quickly adopted by policy as aircraft noise impact estimation method for Zurich Airport.

The most important feature of the ZFI index is that it combines measures of effect and population density measures within a single figure. This figure expresses the net noise effect as the sum of the number of *highly annoyed* persons within the noise exposure contour of 47 dB(A) for the day ($L_{Aeq,06\text{-}22h}$) and the number of *highly sleep disturbed* persons within the noise exposure contour of 37 dB ($L_{Aeq,22\text{-}06h}$) at night. These choices do not imply any scientifically founded effect threshold, but are basically normative settings. For the 'day' period, 5 dB penalties are charged during the hours 06-07 h and 21-22 h. To derive the number of highly annoyed persons (HA), for each hectare grid point within the relevant contour, the percentage highly annoyed (%HA) is derived based on the exposure-effect function for aircraft noise annoyance by Miedema & Oudshoorn (2001). The resulting percentage is multiplied with the number of residents within the hectare and the result is summed up within the exposure contour (which also defines the relevant perimeter). Presently, the area covered by the 47 dBA ('day') contour amounts to about 450 square kilometers, with about 400,000 residents, of which roughly 30,000 are considered highly annoyed by aircraft noise (Volkswirtschaftsdirektion des Kantons Zürich 2008).

To assess aircraft noise effects during night time, in analogy to the concept of *highly annoyed*, the measure "highly sleep disturbed" (HSD) was conceived. In contrast to the HA component, HSD cannot be calculated from average exposure, but is based on the distribution of maximum sound pressure levels per hectare grid point and their potential to evoke awakening reactions. The maximum sound pressure levels on the ground for each single flight are calculated using the radar flight track records from the year the index is calculated for (Empa 2006). The awakening probability as depending on the maximum sound pressure level of single aircraft noise events is calculated with a function derived from a large field study carried out by Basner and collaborators (2006). Based on the number of individual events and their awakening probability, the total number of awakening reactions of an average person per night living within the respective hectare is assessed. From this number, an arbitrary link function estimates a probability to be "highly sleep disturbed". Again, this probability is multiplied with the number of residents within the hectare, yielding the indicator HSD.

Finally HA and HSD are added together, resulting in the single value ZFI. The detailed calculation rule of the ZFI is documented in Empa (2006). Practical experiences and some figures are reported in (Schäffer et al. 2010). The index is currently calculated and reported to the public by the government on a yearly basis in order to allow everyone to gauge the development of the noise situation around the airport. The last available annual calculation was made for the year 2009 and is reported in Empa (2010).

There is room for improvement of the ZFI for several reasons: The definition of the calculation perimeter for the HSD component is not primarily effect-oriented, but arbitrarily set along a 'traditional' average exposure contour although the HSD component is derived from awakening probability which is assessed from maximum sound pressure levels. Although localized exposure-response relationships for the Zurich Airport area are at hand now (e.g. in Brink et al. 2008), they were missing at the time the ZFI was developed. Therefore, the choice was made for a well-established dose-response function (Miedema & Oudshoorn 2001). Although the chosen Miedema/Oudshoorn function pertains to the $L_{dn}$ measure, it is applied to a weighted 16h-$L_{eq}$ in the ZFI. This is explained with the fact, that in the Zurich Airport region, $L_{Aeq,06\text{-}22h}$ is roughly the same as is the $L_{dn}$. The penalization of shoulder hours is rather based on a normative setting than on empirical data. Furthermore, it has been argued that the index is prone to be influenced too much by the sheer population size at the edges of the perimeter, thus accepting an underrepresentation of the considerable noise impact close to the airport – in the center of the perimeter (Oliva 2006).

### The system of noise indexes used at Frankfurt Airport (FFI and FNI)

As part of the development of the so called "Anti-Noise-Pact" (ANP) at Frankfurt Airport, the chairman of the "Regionales Dialogforum Flughafen Frankfurt" (RDF, regional forum for the dialogue at Frankfurt Airport) proposed – in contrast to the one-value-approach adopted for the ZFI at Zurich Airport – *two* noise indexes for monitoring the aircraft noise situation at Frankfurt Airport. The indexes are called the "Frankfurt Aircraft Noise Index" (FFI) and the "Frankfurt Night Index" (FNI). Whereas the primary index FFI calculates the number of people highly annoyed by aircraft operations around Frankfurt Airport, the FNI is meant to supplement FFI – it assesses nocturnal air traffic effects by expressing the number of awakenings due to aircraft noise at night-time. Both FFI and FNI combine exposure measures and population density measures within a single number.

On December 12th in 2007, in a joint declaration, the air transport industry and the State of Hessen supported the concept of noise assessment based on noise effect indexes with reservation, i.e. only if the proposed indexes are subjected to a scientific evaluation. A group of researchers (Schreckenberg et al. 2009) were commissioned to evaluate, from a scientific viewpoint, whether a regional index is principally suitable to assess aircraft noise development due to changes in number, spatial distribution and type of flights and whether the proposed indexes fulfil the following requirements: (1) The indexes should be a transparent description of the regional aircraft noise development. (2) They should reflect the effects of active noise control measures and they should provide a comparative tool to assess advantages and disadvantages of active noise control measures. (3) At least one of the proposed indexes should be suitable for the definition of a regional noise limit, where countermeasures should be triggered if the limit is exceeded. The results of the evaluation have been documented by Schreckenberg et al. (2009).

### Differences and similarities between ZFI and FFI

The primary aircraft noise effect index FFI describes the number of persons highly annoyed by aircraft noise (HA) in areas within the 53 dB(A) $L_{eq,06\text{-}22h}$ contour. The 53 dB(A) $L_{eq,06\text{-}22h}$ contour was chosen by the RDF in order to only account for 'relevantly' noise-burdened residents in the index. In contrast to the ZFI, which relies on the generalized exposure-annoyance function by Miedema & Oudshoorn (2001), a regional exposure-response curve is incorporated in the FFI, based on data of a field study on aircraft noise annoyance carried out in communities in the vicinity of Frankfurt Airport in 2005 (Schreckenberg & Meis 2006). The FNI serves to assess the effect of nocturnal air traffic by reflecting the number of additional awakenings induced by aircraft noise between 22 h and 6 h, including regions where at least 0.75 additional aircraft noise induced awakenings per night are expected. As is the case with the ZFI, the awakening probability function from Basner et al. (2006) is used for this purpose. 0.75 additional awakenings is a normative setting.

Since the beginning of this year, the indexes FFI/FNI serve as the primary planning tool of the RDF, the Regional Forum for the Dialogue at Frankfurt Airport and are used by the Forum to suggest and negotiate active noise abatement measures with the airport authorities.

ZFI and FFI/FNI share many conceptual similarities, but differ in some aspects. First, it must be mentioned that the FFI was conceived only after some initial experience with the ZFI was at hand. While the ZFI index uses two different effect measures to be integrated into one single figure, the FFI covers the 16-hour day period but regards only annoyance as effect measure. The FNI gives supplemental information on night noise impact, thus avoiding the delicate issue of combining different effects in a single number. Last but not least is the ZFI index part of the cantonal public law and thus has legal force, which is not the case for the FFI.

## CONCLUDING REMARKS

The strengths of noise effect indexes are that they (1) express the effects of a certain exposure scenario of a whole airport in one single figure (per effect dimension), and (2) all residents that, according to objective criteria, belong to the basic calculation perimeter, are accounted for in the index and weighted according to the effective noise burden they carry. Noise effect indexes thus overcome the primary weakness of traditional noise assessment, whose focus is rather on *exposure* than on *impact*. Using indexes, the overall noise effect is reflected more accurately in the resulting figure than simply the counting of residents within a particular noise contour. Noise effect indexes can be used to compare the full range of the noise damage assignable to operating regimes at airports, e.g. in order to be able to choose the least burdensome one. If combined with a limit value that should not be exceeded by an airport as a whole, they can generate political pressure to enforce stronger and more effective means of active noise abatement.

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# Differential exposure of the urban population to road traffic noise in Hong Kong

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## INTRODUCTION

Recent studies have shown that biased environmental policy and enforcement, combined with differential market forces, may lead to disproportionate exposure of certain population groups in the society to environmental pollution (Brainard et al. 2002, 2004). The term “environmental inequality” refers to the unequal distribution of environmental risk or burden in the society (Pellow 2000; Brainard et al. 2002, 2004). Its synonymous term “environmental justice” concerns the broader dimension of fair treatment of all people regardless of ethnicity, age, socio-economic status with respect to the environment (USEPA 2011). In recent years, increasing attention has been given to the unequal exposure of environmental nuisances to air pollution (Baum et al. 1999; Brainard et al. 2002) and noise (Brainard et al. 2004; Hoffman et al. 2003; Pearce et al. 2006).

Noise pollution is an important aspect of environmental quality because of its prominence in many cities, ease to be quantified and potential health impacts (Stansfeld et al. 2000). Hong Kong offers a good opportunity to study environmental inequality. Having an urban acoustic environment dominated by road traffic noise (Brown & Lam 1987), an estimated 18 % of the population is exposed to excessive road traffic noise (HKEPD 2006). Furthermore, Hong Kong’s dualistic private and public housing provision mechanism offers a unique experience for the study of environmental inequality. From the social perspective, Hong Kong has a high Gini coefficient which is indicative of significant income inequality (Legislative Council Secretariat 2004).

Little research has been carried out so far in Hong Kong to ascertain if, and to what extent, noise exposure is class-biased, and whether the lower socio-economic stratum is more susceptible than others to environmental noise. The primary objective of the study is therefore to investigate the extent to which differences in road traffic noise exposure are related to the socio-economic status of the urban inhabitants in Hong Kong.

## METHODOLGY

To obtain the necessary data for analysis, both noise exposure and socio-economic data are needed. The former was done by noise mapping and the latter obtained from the Census Department. Based on census data, the size of the study unit was determined by the census enumeration unit. Theoretically, the smaller the census unit, the less heterogeneous and the more representative is the data.

### Study unit

The study chose to use the smallest census enumeration unit available in Hong Kong. In using the census data, the study recognized the related limitations and noted at the same time that such an approach has been used in previous studies (e.g. King & Stedman 2000; Jerrett et al. 2001; Levy et al. 2002; Brainard et al. 2004). In Hong Kong, a former study focusing on air pollution exposure also used census data at the Tertiary Planning Unit (TPU) level (Wong et al. 2008).

This study used the smallest census unit, the Building Group (BG), which is a cluster of residential buildings with relatively homogeneous socio-economic characteristics. The BG is the smallest census tract in Hong Kong and has, typically, a minimum of 1,000 people. 570 BGs from among the total of 2,817 BGs in 2001 in Hong Kong were selected. Covering all 17 electoral districts (except islands), this sample was randomly selected to represent public and private housing clusters, geographical districts, housing age and socio-economic characteristics.

### Noise exposure estimates

Another key issue for environmental inequality studies is the assessment methodology. Conducting *in-situ* noise measurement was considered impractical because of time and resource constraints. A cost-effective alternative is to use the noise modeling approach (Brainard et al. 2002, 2004). Noise exposure estimates for a large area is modeled and predicated fairly accurately and quickly (Lam et al. 1999; Law et al. 2011).

Using the software LIMA, noise exposure estimates were obtained at 1 m from the façade of selected buildings. Data such as topography, gradient of roads, heights of buildings, traffic flow, percent heavy vehicles, traffic speed, were all obtained from the government for the year 2001. Noise mapping results were projected on the façade of buildings and exported to spreadsheets. The noise exposure estimates at different receptors in a BG were expressed in terms of statistical descriptors, including the mean of $L_{10}$ and the percentage of BGs exposed to 70 dB ($L_{10}$) or higher, for subsequent analyses.

### Socio-economic characteristics

Socio-economic characteristics of each BG were derived from the latest census conducted in 2001. They covered all key variables including age, language, education, economic inactivity, occupation, tenancy, household size, crowdedness, monthly household income, poverty and social deprivation index.

Since these socio-economic indicators are highly inter-correlated, it is hence difficult to interpret the results. A way to overcome this problem is to use composite indices of socio-economic parameters (Brainard et al. 2002; Pearce et al. 2006). An example is the socio-deprivation index (SDI) which is a measure of the level of deprivation (Pearce et al. 2010). It comprises of a number of social and economic parameters, including, but not limited to, income, employment, health, education, housing ownership, living environment and car ownership (Pearce et al. 2010)

In the SDI of this study, five socio-economic parameters were selected: education, social class in terms of occupation, overcrowding, non-ownership and poverty. Each of the socio-economic parameters in the SDI was then calculated into a z-score and standardized on the same scale, centering at zero.

## Decile analysis

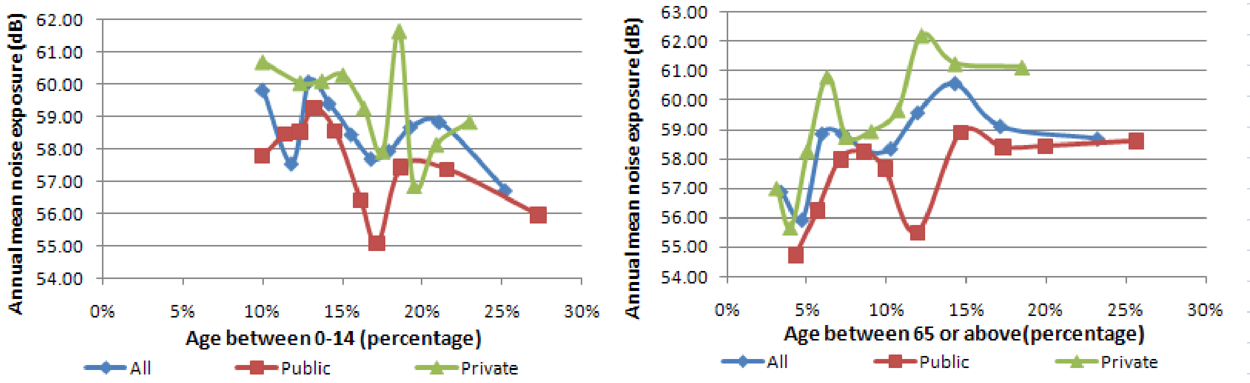
Decile analysis is commonly used in environmental inequality studies (Brainard et al. 2004; Pearce et al. 2006; Braubach & Fairburn 2010; Pedersen 2011) to present trends and patterns graphically. The decile method sorts the socio-economic data in ascending order and obtains the average for the deciles. Mean values of the noise exposure estimates are also calculated for corresponding decile groups (Mitchell & Dorling 2003).

One point merits attention is that due to different socio-economic characteristics of public and private housings in Hong Kong, simply plotting the decile percentages of the socio-economic parameter on a horizontal axis would be difficult to generate meaningful relationships between socio-economic variables and noise exposure. Hence, the decile plots in this study are expressed in absolute decile values on the horizontal axis.

RESULTS

## Age

Age in this study is categorized into four groups: 0-14, 15-39, 40-64 and ≥ 65 years of age. The percentage in each age group is calculated for every BG. (Figure 1-2) present the results for the first (0-14) and last (≥ 65) age groups. It can be seen that younger people are on the whole relatively more protected from noise exposure than the older people. For instance, the lower decile age group of 0-14 (containing 10 % of the BGs that have the least proportion of population in this age group) is exposed to a mean noise level of 59.7 dB, while the upper decile of this group is exposed to a mean noise level of 56.7 dB. This downward sloping trend means that among the BGs, the greater proportion of people in the 0-14 group, the lower is mean noise exposure. For the ≥ 65 age group, the trend is reversed, meaning that older people are more likely to be exposed to higher levels of noise.



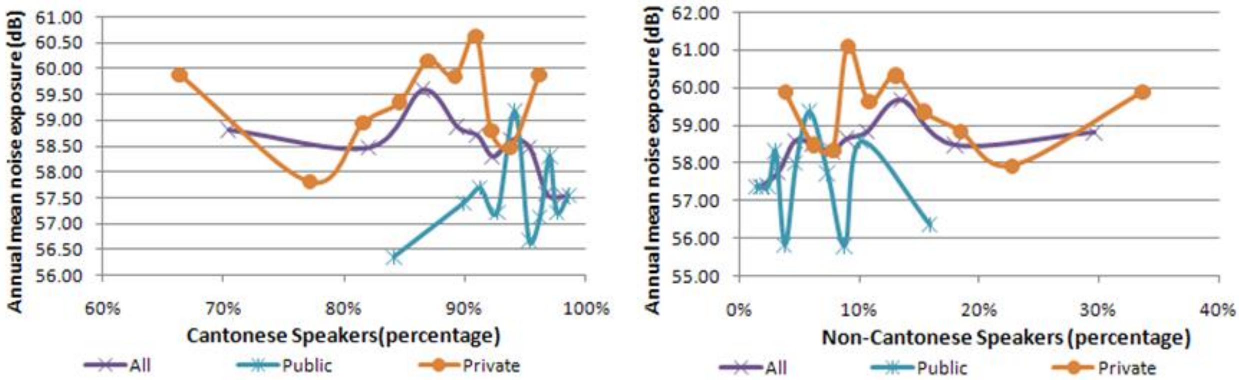

**Figures 1-2:** Mean annual noise exposure by age decile for specified age groups (0-14, left; ≥ 65, right). Each decile has an equal number of BGs

## Spoken language

Spoken language is defined as the "language/dialect a person used in daily communication at home" (CSD 2001, p.71). The population in BGs is categorized into two groups: Cantonese-speaking and non-Cantonese-speaking. Cantonese is the mother tongue of majority of the people whereas new migrants and overseas workers speak other languages.

When we look at all the BGs pooled together for the Cantonese-speaking group, a negative trend is evident, meaning that BGs with higher proportion of Cantonese-speakers are exposed to lower levels of noise (Figure 3). The same observation applies to the ≥ 70 dB group which exhibits a more pronounced negative trend (not shown here). In other words, there is a higher chance of exposing to lower levels of noise if one speaks Cantonese.

As regards the non-Cantonese speakers (mainly Mandarin, other Chinese dialects and English speakers), no distinct pattern or trend can be observed. The only conclusion that could be drawn from these diagrams (Figures 3-4) is that the majority of non-Cantonese speakers live in private housing rather than public housing. Considering the fact that people living in private housing are exposed to higher level of noise, as observed earlier, non-Cantonese speakers are at risk of exposing to higher level of noise compared to the Cantonese speaking population.



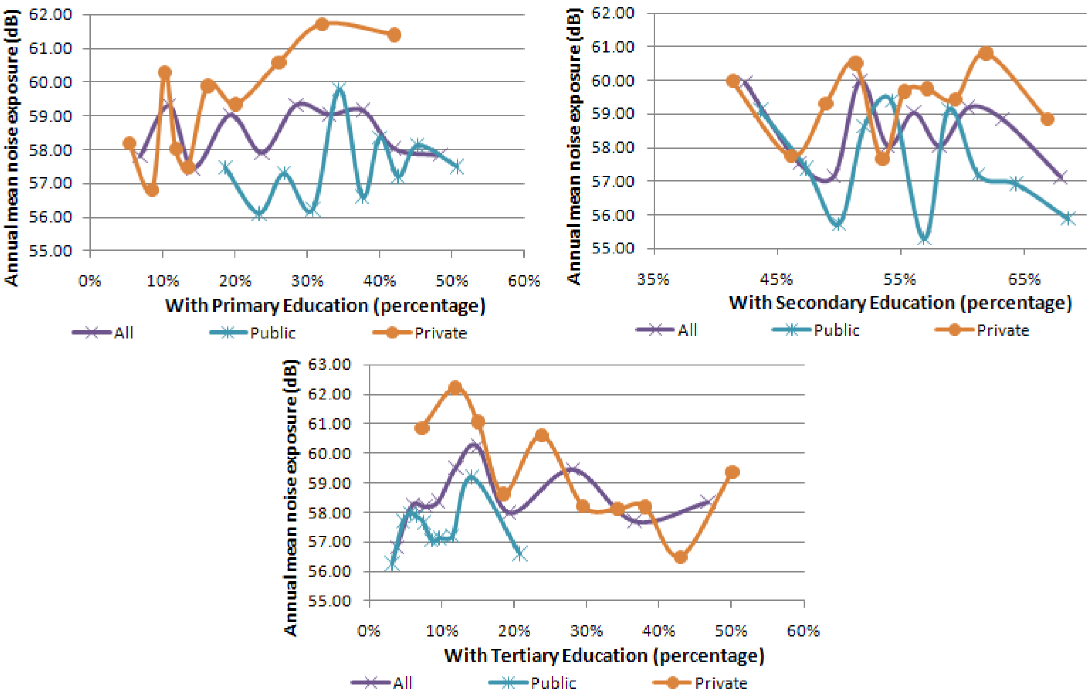

**Figures 3-4:** left: Mean annual noise exposure by Cantonese-speaker decile;
right: Mean annual noise exposure by non-Cantonese speakers decile

## Education

To investigate the effect of education, the population is divided into three groups in the census data according to the "highest level of education attained": primary, secondary and tertiary education. The decile analysis shows (Figures 5-7) a positive trend with respect to primary and tertiary education and a negative trend with respect to secondary education. These results are counterintuitive as one may consider people with higher education level would be able to secure higher income and can thus afford a better living environment.

For population in the private BGs, one could observe a positive trend in the primary education group but a negative one in the secondary and tertiary education group. This indicates that for people living in private houses, the assumption that higher education leads to better living environment generally holds. However, in the public BGs, except for the secondary education group in which a negative trend is observed, no obvious trend can be observed. The same general pattern is also evident from the ≥ 70 dB data.

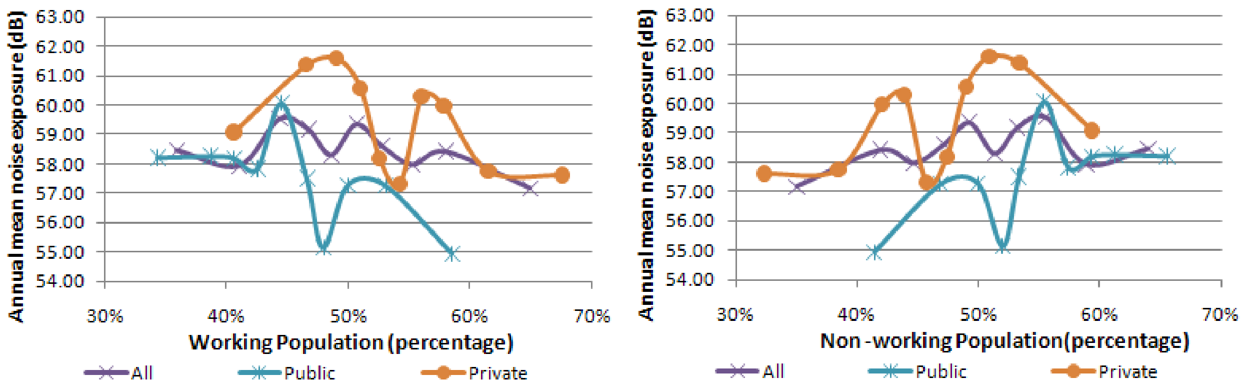
Two conclusions could be drawn from these findings. First, the level of education has a greater effect in people living in private housing than public housing in relation to noise exposure. Second, for private housing, people attaining either low or high education level tend to suffer more from noise pollution. For these reasons, no distinct pattern could be depicted if the public and private BGs are pooled together. The trends are more prominent if they are portrayed individually.




**Figures 5-7:** Top left: Mean annual noise exposure by primary education decile; Top right: by secondary education decile; Bottom: by tertiary education decile

## Employment and occupation

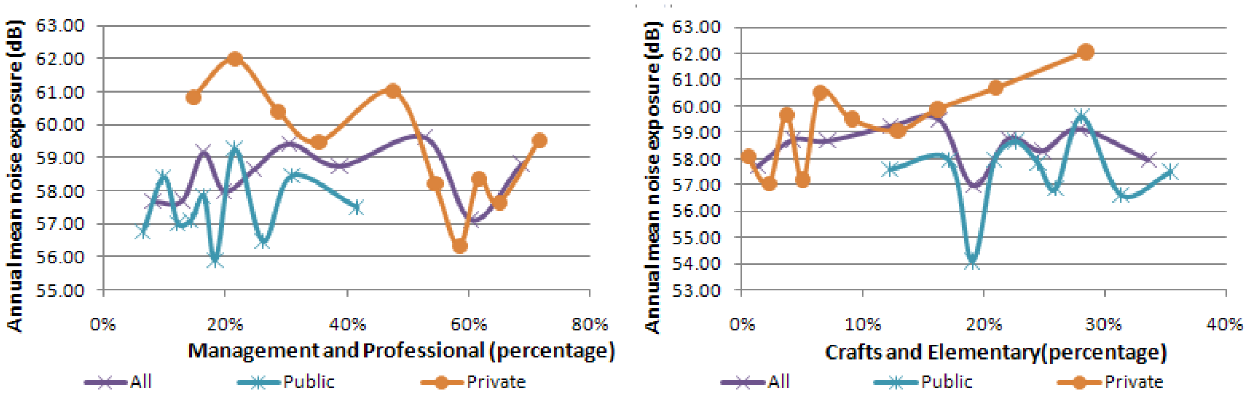
Again, the trends are more evident if the public and private BGs are considered separately. There is a general downward sloping trend in the working population group but an upward sloping trend in the non-working population (Figures 8-9). This means that in BGs where more people work, individuals are less likely to be exposed to noise. This is a more apparent pattern among the public BGs. For the public BGs, the difference between the higher and lower decile is 3.26 dB. The difference is only 1.46 dB among the private BGs. In other words, the effects of occupation is more on residents of public housing than in private housing irrespective of whether or not they are working.




**Figures 8-9:** Left: Mean annual noise exposure by working population decile; right: Mean annual noise exposure by non-working population decile

In examining the effect of occupation, the population is further divided into a number of occupation categories: managers and administrators, professionals, clerks, crafts and related workers, elementary occupation. The results are shown in Figures 10-11.

In private BGs, those having a greater proportion of managers and professionals are exposed to lower levels of noise. This trend is reversed for in the craft and elementary occupation group. For the public BGs, no clear linear relationship could be observed. This is understandable as people that are eligible for public housing must meet certain income requirements. Analysis of the relationship between occupation and noise shows that, first, occupation matters more for people living in private housing than public housing. Second, for those who live in private housing having a job with a higher social status is likely to be exposed to relatively less noise.




**Figures 10-11:** Left: Mean annual noise exposure by management and professional decile; right: Mean annual noise exposure by crafts and elementary decile

## Income

The effect of household monthly income is also examined in this study. A very clear pattern has emerged: BGs with a higher proportion of high-income households are exposed to relatively less noise. This is applicable to public BGs (difference between the lower and upper decile: 2.14 dB), private BGs (3.77 dB) and all BGs pooled together (1.84 dB). This effect is more pronounced than any other variables examined. It is also in line with our earlier observations with respect to *surrogate* indicators, such as occupation, household size and education.

## SDI

For the public BGs, the difference in mean noise level between the most deprived BGs and the least deprived ones is 0.31 dB. Nevertheless, the corresponding figure for private BGs is considerably larger. The least deprived private BGs receive a mean noise level of 57.2 dB, while the most deprived ones receive 61.3 dB. The corresponding figures for the ≥ 70 dB group can provide a better picture of inequality in noise exposure between the worse-off and the better-off people living in private housing. For the least deprived private BGs at the lower decile, only 4 % of them are exposed to noise exceeding 70 dB (the traffic noise planning standard of Hong Kong), whereas the corresponding figure for the upper decile is 17.45 %. All the results suggest that the most socially-deprived population living in private housing is most vulnerable to noise.

## Regression analysis

Regression analysis was carried out to find out whether or not the traffic noise exposure level can be explained by socio-economic variables. The dependent variables include the mean noise level and percent of dwelling ≥ 70 dB. Three separate sets of regression analyses were carried out - all BGs pooled together, public BGs and private BGs.

With regard to all BGs, it is found that noise exposure is associated with all variables related to age. The variable "median age" is found to have a strong positive relationship with mean noise level, suggesting that older people are more likely to be exposed to higher level of noise. This observation is consistent with those from the decile analysis.

As regards public housing estates, the regression analysis has also identified age and employment as significant factors affecting exposure to noise. It is interesting to note that no other socio-economic factors, such as employment, language, income or household size, are significant variables in affecting noise exposure.

Finally, for the private BGs, a number of socio-economic variables are identified by the regression analysis as significant from which a few observations can be made. First, the type of accommodation has considerable effect on noise exposure. Apartment owners are generally less exposed to noise than tenants. Second, people with higher level of education tend to be less exposed to noise. Third, occupation is a significant factor affecting one's exposure.

## CONCLUSIONS

Decile and regression analyses have shown that in Hong Kong, people with a lower socio-economic status are exposed to slightly higher levels of road traffic noise. This differential exposure is higher among those living in private housing estates than in public housing. This is because public housing in Hong Kong is provided only for the low income group. Of the various socio-economic variables examined, age, occupation and household income are more significant factors contributing to differential noise exposure.

This study has also found that public housing estates are generally less exposed to traffic noise, probably due to their location in newly developed areas where there is less traffic. This is the inadvertent effect of the public housing provision mechanism which moderates the market force that pushes people of lower socio-economic status to areas of lower environmental quality. Further research is needed to probe into the interplay of market and government forces which foster and/or moderate environment inequality.

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# Human response to vibration in residential environments: Establishing exposure-response relationships

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## ABSTRACT

This paper presents results from a large scale study investigating the human response to vibration in residential environments. The main aim of this study was to derive exposure-response relationships for annoyance caused by vibration experienced within residential properties from sources outside of residents' control. The study took the form of a questionnaire administered to UK residents in their own homes to determine self reported annoyance caused by vibration from a variety of sources along with measurements of vibration inside and outside residences to determine vibration exposure. In total, 1,431 case studies were conducted encompassing railway, construction, and internal vibration sources. Presented in this paper are the results of analyses which were conducted to determine the most appropriate descriptor for vibration exposure in residential environments for the dataset generated by this project. The main considerations for these analyses were the type of averaging used and frequency weighting. Following this, exposure-response relationships are presented for different vibration sources. The relationships take the form of curves indicating the percentage of people expressing annoyance above a given threshold for a given vibration exposure. Combined effects of vibration and noise exposure are also considered. [Work funded by the Department for Environment, Food and Rural Affairs (Defra) UK].

## INTRODUCTION

For a given environmental stressor, exposure-response relationships are a vital tool for the prediction of the effect this stressor is likely to have on the population. Stemming from the pioneering work of Schultz (1978), internationally accepted exposure-response relationships have been developed for annoyance due to noise exposure which describe the proportion of the population expected to express annoyance above a given threshold for a given noise exposure (Miedema & Oudshoorn 2001). No such consensus has been arrived at for the assessment of annoyance due to whole body vibration in residential environments. This paper presents the results of a large scale study funded by Defra investigating the human response to vibration in residential environments (Waddington et al. 2011). The main aim of this study was to develop exposure-response relationships for vibration experienced in residential environments. Vibration sources considered were those outside of residents' control; namely vibration caused by railway traffic, construction work, and internal sources. Response data regarding annoyance caused by vibration and noise exposure were collected via face to face interviews with residents in their own homes. Vibration exposure was determined via measurement and prediction in such a way that, where possible, an estimation of internal vibration exposure was established for each residence in which a questionnaire was completed. From the data collected via this field study, exposure-response relationships have been derived.

## BACKGROUND

The main source of literature concerned with the human response to vibration in residential environments derives from studies into annoyance caused by railway vibration. In a field survey conducted in Scotland (Woodroof & Griffin 1987), annoyance caused by railway induced building vibration was evaluated via a questionnaire with residents and measurements of vibration within a limited number of properties. By correlating different measures of vibration exposure against reported annoyance, it was found that the most appropriate descriptor for describing annoyance for this study was the number of train passes which occurred in a 24-hour period with annoyance found to increase with the number of train passes.

A field study has been conducted in Norway (Turunen-Rise et al. 2003; Klæboe et al. 2003a, b) with the aim of deriving an exposure-response relationship for community response to vibration caused by road and railway traffic. In this study, a social survey was conducted via telephone interview with 1,503 respondents to determine people's reaction to vibration experienced within their own homes. Vibration exposure was predicted in each respondent's property via a semi-empirical model. Logistic and ordinal logit regression models were then used to develop exposure-response relationships for annoyance caused by road and railway induced vibration.

In a recent study by the Transit Cooperative Research Program (Zapfe et al. 2009), a field study was implemented in the USA and Canada with a view to developing criteria for acceptable levels of railway induced groundborne noise and vibration in residential buildings. The main aim of this study was to develop an exposure-response relationship for predicting community annoyance due to groundborne vibration and noise caused by railway systems. The study consisted of questionnaires administered via telephone with 1,306 respondents along with measurements of external vibration. In this study, around 200 different noise and vibration descriptors were considered as potential independent variables for an exposure-response relationship. It was found that all of the calculated metrics were highly correlated with each other and it was therefore concluded that any of the descriptors would be as good a predictor of annoyance as any other. Exposure-response relationships calculated using a logistic regression model were presented for groundborne vibration using highest magnitude of vibration velocity level (*Vdb*) in any given 1/3 octave band as a predictor.

## FIELD SURVEY

### Social survey

The main aim of the fieldwork for the study described in this paper was to establish a database of response data for annoyance due to environmental vibration along with estimations of internal vibration exposure for each respondent. Response data were collected via face-to-face interviews with residents in their own homes (Condie et al. 2011). The questionnaire was presented as a neighborhood satisfaction survey and gathered information on, among other things, annoyance caused by vibration and noise exposure. The social survey questionnaire collected annoyance ratings on five-point semantic and eleven-point numerical scales for potential sources of vibration and noise in the residential environment including railway, construction activity and internal activities. Each questionnaire took, on average, 20 minutes to complete. In total, 1,431 questionnaires were completed with 931 focusing on railway sources, 350 focusing on construction sources, and 150 focusing on internal sources outside of the resident's control. Following the completion of a questionnaire, the respondent was asked if they were willing to allow a measurement of vibration to be conducted in their property at a later date.

### Determination of vibration exposure from railway activities

Properties within a distance of around 70 m from railway lines in the North-West and Midlands of England were targeted. Potential survey sites were identified via desk studies followed by a site reconnaissance to assess the suitability of the site (Peris et al. 2011). The vibration measurement approach consisted of long term (24-hour) monitoring at an external position along with synchronised "snapshot" measurements within respondents' properties. By determining the velocity ratio between the two measurement positions, it was possible to estimate 24-hour internal vibration exposure (Sica et al. 2011). In total, 149 long term measurements along with 522 snapshot measurements were conducted.

### Determination of vibration exposure from construction activities

Three construction sites were targeted on which a new light transit system was being constructed close to residences (Peris et al. 2011). The measurement approach adopted for railway was found to be impracticable for measuring construction activity vibration due to the unpredictable hours of operation and the dynamic nature of the source. Therefore, the measurement approach for construction vibration required more emphasis on extrapolation and correction of measured levels from one location to estimate exposure in other locations (Sica et al. 2011).

### Determination of vibration exposure from internal sources

Residential flats were selected for the investigation of internal sources of vibration. The vibration measurement approach was based on long-term monitoring at strategic positions in the buildings. The levels of vibration exposure from internal activities were found to be very low in comparison to the railway and construction sources (Sica et al. 2011). Reported annoyance caused by this source was also found to be low (Condie & Steele 2011). Therefore the data collected for this source was not deemed suitable for the derivation of exposure-response relationships.

## SELECTION OF VIBRATION EXPOSURE DESCRIPTOR

One of the key challenges in the formulation of an exposure-response relationship for this study is the determination of the most appropriate descriptor of vibration exposure. Broadly, the two main considerations which go into the selection of the most appropriate descriptor are the type of averaging and frequency weighting.

Numerous descriptors of vibration exposure were calculated from 24-hour acceleration time histories of internal vibration. Table 1 provides a summary of the vibration exposure descriptors considered. For railway vibration, these descriptors were calculated for each case study using all train events recorded during a 24-hour period; a train event was defined by its 10 dB down points. Additional to the descriptors presented in Table 1, 1st, 5th, 10th, 50th, 90th, 95th, and 99th percentiles were also calculated.

A principal component analysis was conducted on the descriptor space to attempt to reduce the number of descriptors considered. From this analysis it was found that the different descriptors were well correlated with each other suggesting that, for the database under consideration, the type of averaging used is largely unimportant.

**Table 1**: Summary of vibration exposure descriptors considered. Where $\ddot{x}(n)$ is an acceleration time series, *N* is the number of samples in the acceleration time series, and *T* is the duration of the event in seconds

| Descriptor | Calculation | Descriptor | Calculation |
|---|---|---|---|
| Root mean square ($m/s^2$) | $\ddot{x}_{rms} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\ddot{x}(n)^2}$ | Skewness | $S_k = \frac{1}{N \cdot \sigma^3}\sum_{n=1}^{N}(\ddot{x}(n) - \overline{x})^3$ |
| Root mean quad ($m/s^2$) | $\ddot{x}_{rmq} = \sqrt[4]{\frac{1}{N}\sum_{n=1}^{N}\ddot{x}(n)^4}$ | Kurtosis | $K_t = \frac{1}{N \cdot \sigma^4}\sum_{n=1}^{N}(\ddot{x}(n) - \overline{x})^4$ |
| Root mean hex ($m/s^2$) | $\ddot{x}_{rmh} = \sqrt[6]{\frac{1}{N}\sum_{n=1}^{N}\ddot{x}(n)^6}$ | Peak particle acceleration ($m/s^2$) | Maximum deviation of the time series from the mean |
| Root mean oct ($m/s^2$) | $\ddot{x}_{rmo} = \sqrt[8]{\frac{1}{N}\sum_{n=1}^{N}\ddot{x}(n)^8}$ | $L_{max}$ (dB re $1x10^{-6}$ $m/s^2$) | Maximum 1 second exponential average *rms* over an event |
| Vibration dose value ($m/s^{1.75}$) | $\ddot{x}_{VDV} = \sqrt[4]{\frac{T}{N}\sum_{n=1}^{N}\ddot{x}(n)^4}$ | $L_{eq}$ (dB re $1x10^{-6}$ $m/s^2$) | $L_{eq} = 20\log_{10}\left(\frac{\ddot{x}_{rms}}{1E-6}\right)$ |
| Mean ($m/s^2$) | $\overline{x} = \frac{1}{N}\sum_{n=1}^{N}\ddot{x}(n)$ | $L_E$ (dB re $1x10^{-6}$ $m/s^2$) | $L_E = 20\log_{10}\left(\frac{\ddot{x}_{rms}}{1E-6}\right) + 10\log_{10}(T)$ |
| Standard deviation | $\sigma = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(\ddot{x}(n) - \overline{x})^2}$ | | |

There are a number of different frequency weightings suggested in national and international standards which are intended to reflect the frequency dependence of whole body vibration perception. It was found that application of the appropriate frequency weightings recommended in BS 6472-1:2008 (BSI 2008) and ISO 2631-1:1997 (ISO 1997) resulted in an improvement over unweighted vibration exposure in the Spearman's correlation coefficient against the annoyance responses.

Based on these results, in this paper vibration exposure will be assessed according to BS 6472-1:2008 (i.e. Vibration Dose Values (*VDV*) using the $W_b$ weighting for vibration in the vertical direction and the $W_d$ weighting for vibration in the horizontal direction).

## EXPOSURE-RESPONSE RELATIONSHIPS

### Statistical model

The statistical model used to formulate the exposure-response relationships presented in this paper is based upon the model proposed by Groothuis-Oudshoorn & Miedema (2006). The relationships take the form of curves indicating the percentage of people expressing annoyance above a given threshold (*C*) for a given vibration exposure (*X*):

$$p_C(X) = \text{Prob}(1 - \Phi\left[\frac{C - \mathbf{X}\boldsymbol{\beta}}{\sigma}\right]) \tag{1.1}$$

where $\Phi$ is the cumulative normal distribution function, $\mathbf{X}$ is a vector of vibration exposures, $\boldsymbol{\beta}$ are model coefficients to be estimated, and $\sigma$ is the standard error. The coefficients of this model were estimated via maximum likelihood.

The annoyance thresholds *C* reported will be 28 %, 50 %, and 72 % of the annoyance scale which will be referred to "*percent slightly annoyed*" (*%SA*), "*percent annoyed*" (%A), and "*percent highly annoyed*" (*%HA*) respectively. Respondents stating that they are unable to feel vibration have been recoded to the lowest category on the annoyance response scale.

### Exposure-response relationship for railway vibration

Figure 1 presents exposure-response relationships showing the proportion of respondents reporting annoyance above a given threshold for a given exposure to railway induced vibration. Vibration exposure was calculated based on guidance provided in BS 6472-1:2008. The relationships are shown in terms of $VDV_{b,24hr}$ for vibration in the vertical direction and $VDV_{d,24hr}$ for vibration in the horizontal direction.

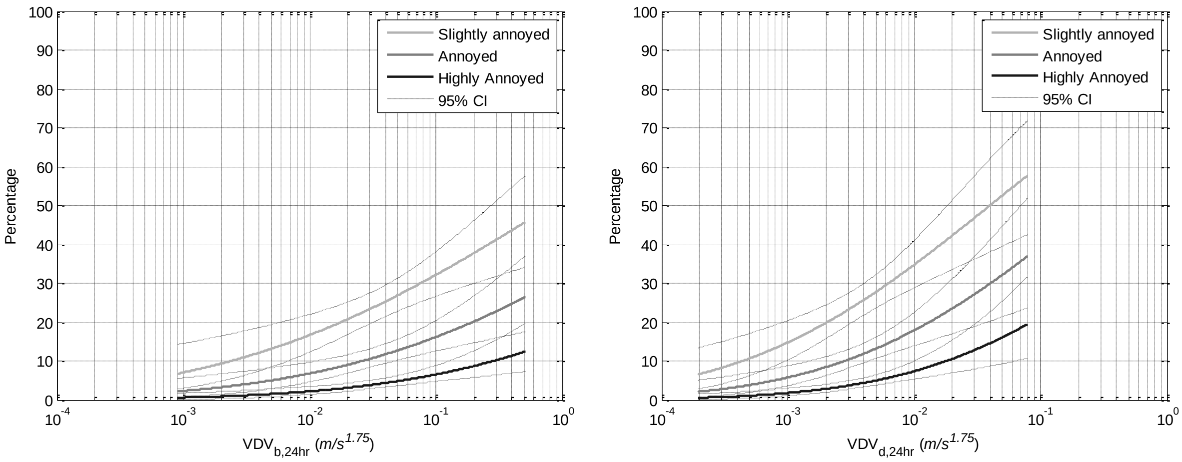


**Figure 1**: Exposure-response relationship showing the proportion of people reporting different degrees of annoyance for a given vibration exposure caused by railway activities. Curves are shown in their 95% confidence intervals. Left panel: Vertical vibration ($R^2_{pseudo}$ = 0.01, $p$<0.001, $N$ = 752). Right panel: Horizontal vibration ($R^2_{pseudo}$ = 0.02, $p$<0.001, $N$ = 752)

**Exposure-response relationship for construction vibration**

Figure 2 presents exposure-response relationships showing the proportion of respondents reporting annoyance above a given threshold for a given exposure to vibration induced by construction activities. Vibration exposure is expressed in $VDV_{b,8:00\text{-}18:00}$ in the vertical direction.

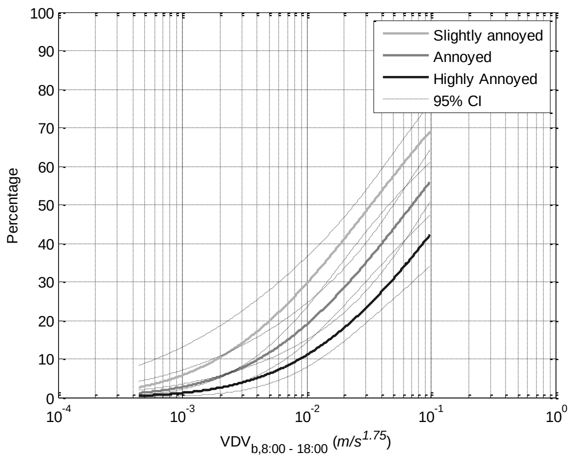


**Figure 2**: Exposure-response relationship showing the proportion of people reporting different degrees of annoyance for a given vibration exposure caused by construction activities. Curves are shown in their 95% confidence intervals. ($R^2_{pseudo}$ = 0.09, $p$<0.001, $N$ = 321)

**Exposure-response relationship for mixed sources**

To investigate the influence of the vibration source type on self reported annoyance due to vibration exposure, data from the railway and construction source types were pooled together and a dummy variable was created for source type. Exposure-response models were calculated with and without the source type variable. The improvement in likelihood for the model with the source variable was found to be significant ($p$<<0.001). This result suggests that the exposure-response relationships for railway and construction sources cannot be combined and a separate relationship is needed for the two different sources. However, it should be noted that differences in the methodology for the estimation of vibration exposure for the two sources may have had an influence on this result.

COMBINED EFFECTS OF RAILWAY VIBRATION AND NOISE

In addition to vibration exposure, noise exposure was determined for each respondent (Koziel et al. 2011). For railway, noise exposures were predicted via the "Calculation of Railway Noise" method (Department of Transport 1995). Exposure-response models were calculated for annoyance caused by vibration using vibration exposure ($VDV_{b,24hr}$ $m/s^{1.75}$) and noise exposure ($L_{DEN}$ $dB$) as independent variables. The improvement in likelihood when noise exposure was included as an independent variable was found to be significant ($p$<0.05). Figure 3 shows the proportion of respondents reporting high annoyance due to vibration for different vibration and noise exposures. It can be seen from this figure that annoyance due to vibration increases with an increase in both noise and vibration exposure. This result suggests an interaction effect between noise and vibration exposure on the total annoyance caused by vibration although it can be seen that vibration exposure has a greater influence.

## CONCLUSIONS

This paper has aimed to give an overview of the main outcomes of the Defra funded project "*Human response to vibration in residential environments*". By means of a large scale field trail, a database of responses for annoyance due to environmental vibration along with estimations of internal vibration exposure has been developed.

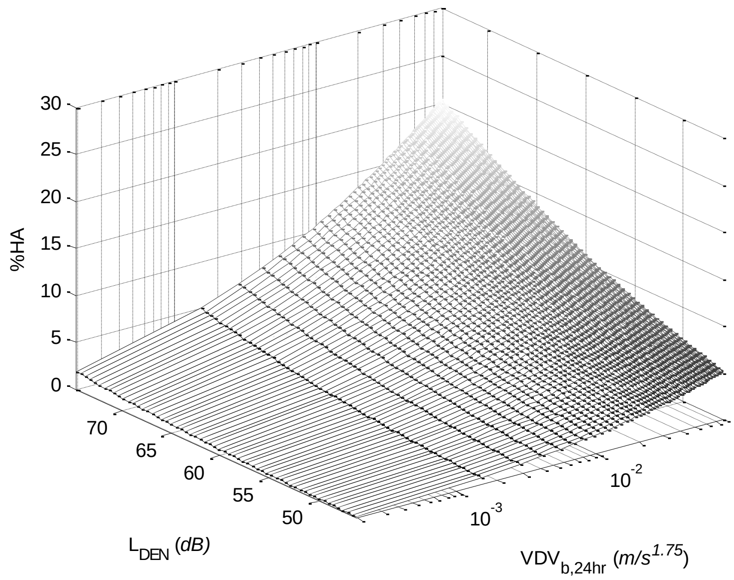


**Figure 3:** Exposure-response relationship showing the proportion of people reporting different degrees of annoyance caused by vibration for a given vibration exposure and different levels of noise exposure. ($R^2_{pseudo}$ = 0.01, $p$<0.001, $N$ = 698)

An analysis of vibration exposure descriptors revealed that, for the dataset under analysis in this project, the type of averaging used was largely unimportant with regards to human response. The application of frequency weightings defined in BS 6472-1:2008 and ISO 2631-1:1997 were found to improve the magnitude of correlation between vibration exposure and self reported annoyance. Exposure-response relationships have been developed for the human response to railway and construction induced groundborne vibration. These relationships have been expressed in terms of *VDV* as per the guidance provided in BS 6472-1:2008. Although not presented in this paper, relationships have also been derived expressing vibration exposure as per the guidance provided in ISO 2631-1:1997 (Waddington et al. 2011). For the case of vibration exposure from internal sources, the low magnitude of both vibration exposure and annoyance made the derivation of an exposure-response relationship impossible. In all of the derived relationships it was found that, as the magnitude of vibration exposure increases so does the proportion of respondents reporting annoyance above a given threshold. Finally, exposure-response relationships for combined noise and vibration exposure have been derived.

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# Quantitative model of combined annoyance caused by simultaneous exposure to outdoor traffic sounds

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## ABSTRACT

Laboratory experiments which include the simulation of simultaneous exposure to the multiple traffic sounds and the assessment of subjective annoyance have been used to study the interaction between the noise sources, it's influence on overall annoyance, and the modeling of exposure-response relationships. The aircraft (or railway) noise annoyance is masked by road-traffic noise and the higher levels the road-traffic noise has, the lower aircraft (or railway) annoyance the subject rates. For combined noise which two sources have similar sound levels or equally annoying levels, the overall annoyance is higher than the maximum source-specific annoyance, while, for combined noise in which the level of one source was 10 dB or higher than that of the other, the overall annoyance was equal to the maximum source-specific annoyance. An annoyance model for a combined noise exposure was developed using a weighted summation method, and the integration of noise perception resembles the summation of the acoustic pressure of each source.

## INTRODUCTION

Several large-scale surveys on the annoyance response to transportation noise have been conducted by the support from the Korean government and the exposure-response relationships for single exposure to aircraft, railway, and road-traffic sounds outdoors have been established by field surveys and reported at ICBEN 2008 (Lee et al. 2008). The results shown that the annoyance response is source-dependent and the responses show a similar trend to the annoyance curves recorded in Japan, although they are somewhat different from those obtained from most European surveys.

There have been a few significant developments diversifying research topics for community noise studies. Targeting sounds have been expanded to include military arms and wind turbines, and the methodologies used to assess the effects of noise on humans have been further developed with a multi-disciplinary approach in mind. Figure 1 shows the exposure-response curves for transportation and wind turbine noise reported in Korea, derived from field and laboratory studies, respectively (Lee et al. 2008, 2011).

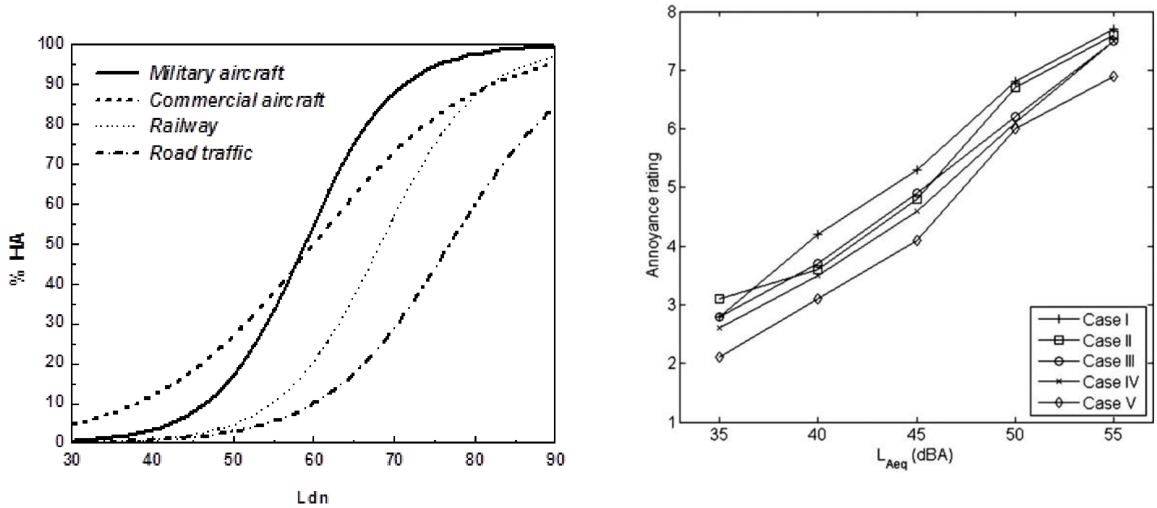


**Figure 1:** (a) %HA for transportation noise (Lee et al., 2008) (b) Annoyance ratings for modulation depth spectrum of wind turbine noise (Lee et al., 2011, modulation depth: Case I> Case II> Case III> Case IV> Case V)

With regard to the practical problems with noise, such as noise mitigation, prevention and policy making, combined effects caused by simultaneous exposure to multiple sounds should be considered. Pearsons points out that the perceived noisiness of aircraft noise decreases as background noise is added (Pearsons 1966). The annoyance reaction to the target noise according to changes in the level of background noise has also been investigated (Wells 1971; Robinson 1972; Powell & Rice 1975). Powell and Rice examined the influence of background noise on the annoyance caused by aircraft noise, and found that there was a trend of decreased aircraft noise annoyance as background noise level increased for a continuous background noise.

Izumi (1988) reported that total annoyance caused by simultaneous railway and road-traffic noise is lower than the source-specific annoyance for railway noise with a relatively low level of road-traffic noise. In conditions in which railway noise was combined with a high level of road-traffic noise, total annoyance was slightly higher than the maximum source-specific annoyance. Taylor (1982) found that total annoyance is lower than the maximum source-specific annoyance from a field study in Toronto. In addition, such results were reported by Berglund et al. (1981) and Yano and Kobayashi (1990), who investigated that total annoyance was higher than or equal to the maximum source-specific annoyance in various combinations of impulsive and traffic noises.

Similar results were obtained from previous research conducted by these authors. Lim et al. (2008) found that a trend of reduced subjective annoyance to aircraft noise if background noise level is high, and a recent field study on the combined annoyance of aircraft and road-traffic noise also shows that the source-specific annoyance of combined noise decreases as the level difference between the sources decreases (Hong et al. 2009).

These findings differ from the idea that annoyance has a linear correlation with the exposed energy and it might seem counterintuitive that annoyance caused by two noise sources is lower than each specific single noise. In this paper, the source-specific annoyance with regard to different levels of road-traffic noise will be investigated, and the interaction between two noise sources is analyzed. An appropriate model for the evaluation of combined noise will then be developed, based on the analyses of the interaction effects.

## METHODS

### Stimuli

Aircraft, railway, and road-traffic were presented as the various combinations of two simultaneous sounds during 15-s periods, and the A-weighted levels of the sounds were separated into 10 dB steps from 40 to 80 dB. Binaural recordings were made to obtain the signals of each noise source, with a dummy mannequin in a field test, and they were fed into a mixing console (Cool Edit Pro *Ver*. 2.0) to produce the combined noise stimuli to simulate combinations of aircraft and road-traffic sounds and railway and road-traffic sounds. They were a total of 50 experimental stimuli.

### Subjects

Forty-one subjects, 20 males and 21 females between the ages of 20 and 40 years, participated in the experiment for rating 25 combined noise stimuli of aircraft and road-traffic sounds (experimental group 1). The other 41 subjects, 21 males and 20 females between the ages of 20 and 40, participated in the experiment for rating 25 combined noise stimuli of railway and road-traffic sounds (experimental group 2). Audiometric screening tests were performed on each subject to examine the hearing thresholds for both ears at the center frequencies of the octave bands. All of the participants had normal hearing [i.e., the hearing level (HL) was smaller than 15.0 dB of the reference equivalent threshold sound pressure level (RETSPL) (ISO 389-1, 1998) in this research].

### Experimental design

The 'Within-Subjects' design was employed for the experiment and the combined noise stimuli of aircraft and road-traffic sounds were randomly played back to experimental group 1 and those of railway and road-traffic sounds were randomly played back to experimental group 2 in a listening room. Subjects were asked to rate the overall annoyance of the two noise sources and the source-specific annoyance of each specific single noise at various noise levels. The eleven-point (0-10) numeric scale recommended by ICBEN was used to rate the subjective annoyance.

## RESULTS

### Interaction between two noise sources

To examine the effects of the interaction between the two noise sources on overall annoyance, the correlation analysis between source-specific and overall annoyance score were performed under every experimental condition. The significance of each correlation coefficient was tested using the T-test comparison. The combination in which the level of one noise source was the same or similar to the other, overall annoyance and source-specific annoyance were significantly correlated ($p<0.05$). At relatively low levels (less than 50.0 dB in aircraft-road combined noise, and less than 60.0 dB in railway-road combined noise), the overall annoyance was correlated with the source-specific annoyance. At relatively high levels, the overall annoyance was correlated with aircraft or railway noise annoyance (not correlated with road-traffic noise annoyance). The cause might be that at peak energy levels, aircraft or railway noise higher than road-traffic noise.

The pair-wise comparison of the mean rating scores for the source-specific and overall annoyance was conducted. The overall annoyance was significantly higher than the maximum annoyance of individual sources if two constituent sounds had a similar level, or they were equally annoying. The results of the Pair-wise comparison are shown in Figures 2 and 3. Figure 2(a) shows the observed overall annoyance and its expected model caused by combined exposure to aircraft and road-traffic sounds with the level of road-traffic sounds fixed at $L_{eq}$ 60 dB. Figure 2(b) shows the overall annoyance as a function of the levels of road-traffic sounds with the level of aircraft sounds fixed at $L_{eq}$ 60 dB.

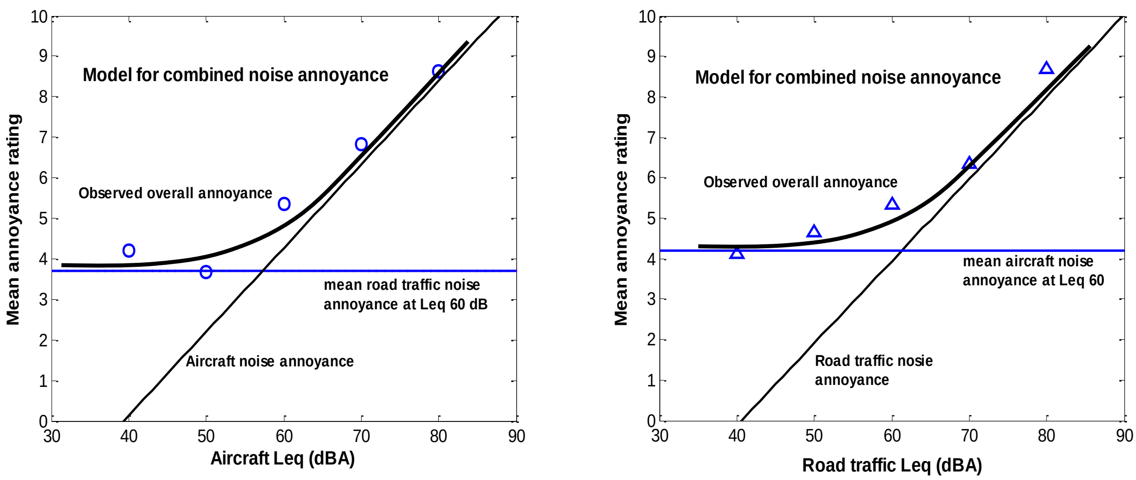


**Figure 2:** (a) Overall annoyance for aircraft noise combined with road-traffic noise at *Leq* 60 dB as a function of the *Leq* of aircraft noise. (b) Overall annoyance for road-traffic noise combined with aircraft noise at *Leq* 60 dB as a function of the *Leq* of road-traffic noise

The observed overall annoyance and its expected model, caused by combined exposure to railway and road-traffic sounds, are shown in Figure 3; in which Figure 3(a) indicates the case of the level of road-traffic sounds fixed at $L_{eq}$ 60 dB, and Figure 3(b) indicates the case of the level of railway sounds fixed at $L_{eq}$ 60 dB.

Kim et al. (2010) conducted a correlation analysis between various noise metrics and annoyance responses and determined that the A-weighted $L_{eq}$ was a good acoustic measure for annoyance responses to short-term noise exposure. To establish the combined annoyance model, the overall level of combined sources has to be defined and the summation of the noise level of each source might be presented as follows.

$$Leq_{overall} = k \log_{10}\left(\sum_{i=1}^{n} 10^{\frac{L_i}{k}}\right) \quad (1)$$

For the summation of the conventional $L_{eq}$'s, an energy summation in a free-field condition, k=10, however, it is obvious that aircraft, railway, and road-traffic cause different annoyance responses and the k-values should be different for each source.

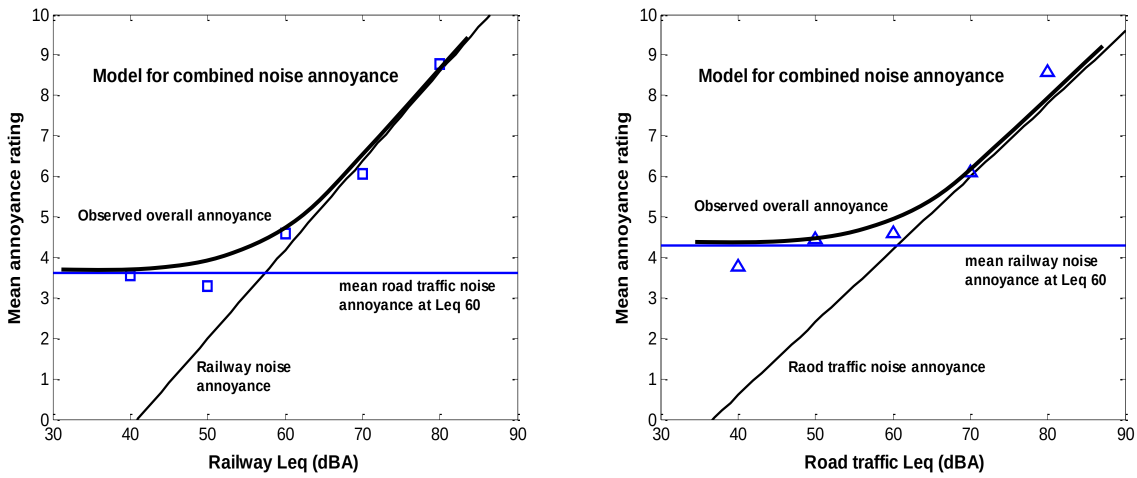


**Figure 3:** (a) Overall annoyance for railway noise combined with road-traffic noise at Leq 60 dB as a function of the *Leq* of railway noise. (b) Overall annoyance for road-traffic noise combined with railway noise at *Leq* 60 dB as a function of the *Leq* of road-traffic noise

First of all, the levels of aircraft and railway sounds have transformed into equally annoying levels of road-traffic sounds with their exposure-response relationships and the equally annoying levels have been obtained by adding a source dependent penalty (or bonus) to the level of the source considered. The equation for the summation of the noise levels of the two noise sources might be presented as follows.

$$Leq_{overall} = k \log_{10}\left(10^{\frac{Leq_{road}}{k}} + 10^{\frac{Leq_{source}+P_{source}}{k}}\right) \quad (2)$$

Varying the parameter k, the best fit model between the $Leq_{overall}$ and overall annoyance was obtained by using a least square method. For aircraft-road combined noise, the variance of errors was minimized when the value of 'k' was about 21. The highest correlation was 0.730 in the range of 'k' from 18 to 24. For railway-road combined noise, the variance of errors was minimized when the value of 'k' was about 19. The highest correlation was 0.767 in the range of 'k' from 16 to 22. In considering the results of both cases, the annoyance model for combined noise with k=20 seems reasonable.

In this experimental study, the procedure of the methodology adopted that of Vos's weighted independent effect model to obtain the combined annoyance model (Vos

1992). The summation of the *Leq*'s of the two noise sources was performed by adding the level-dependent penalties and the parameter k was determined to be 20 in the overall annoyance model. The significant result is that the mental integration in the cognition of two simultaneous sounds resembles the acoustic pressure summation (k=20), rather than the energy summation.

## CONCLUSIONS

For combined noise caused by two sources with similar sound levels or equally annoying levels, overall annoyance was significantly higher than the maximal annoyance of individual sources, while, for combined noise in which the level of one source was 10 dB or higher than that of the other, overall annoyance was equal to the annoyance caused by a dominant source between two sources. The annoyance caused by a dominant source is significantly correlated with overall annoyance in both cases, similar to the results found in a field study of combined noise annoyance (Hong et al. 2009). These results show that the perception and cognition of two simultaneous sounds are performed differently with a summation of the sound energy.

The quantitative model of combined noise annoyance demonstrates that a mental integration of noise perception (i.e. annoyance) caused by two simultaneous traffic sounds resembles the summation of the acoustic pressure of each source, rather than the summation of the $L_{eq}$'s, and consequently, two equal levels, in terms of $L_{eq}$, yield an overall noise level which is 6.0 dB higher than each individual source level. However, Vos (1992) proposed that two equal levels yield an overall noise level which is 4.5 dB higher than each individual source level. The difference might be derived mainly from the difference of annoyance rating conditions (indoor vs. outdoor) and the range of the level difference of two noise sources was expanded to 40 dB in this study while the range was limited to 15-20 dB in Vos's study. However, the findings in this study explain Flindell's proposal, in which the pressure *Leq* was superior to the conventional (energy average) $L_{eq}$ (Flindell 1983). Further research with various noise sources and differing annoyance rating conditions should be conducted to apply a summation of the acoustic pressure for the combined annoyance model of traffic sounds.

## ACKNOWLEDGEMENTS

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# Dose-response relationships for aircraft noise annoyance in Ho Chi Minh City and Hanoi

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## INTRODUCTION

Community noise-control policies and guidelines on mitigating noise have been laid down in many developed countries, especially in Europe (European Communities 2002). Noise effects in developing countries are continuing to grow because of rapid urbanization in addition to bad planning and poor construction of buildings. However, environmental noise in these countries is insufficiently controlled because of the unavailability of adequate data. The data are insufficient to propose dose-response relationships and to establish appropriate criteria. Therefore, there is an urgent need to accumulate a reliable dataset to establish the relationship between noise and community annoyance in developing countries for both national and global noise management.

In order to meet this requirement, community response to transportation noise has been investigated in Vietnam's two largest cities, Hanoi and Ho Chi Minh City, since 2004. It has been found that the Vietnamese were less annoyed by road traffic noise by about 5 dBA than European people (Phan et al. 2010). The dose-response relationships for the Vietnamese were established for road traffic noise exposure and annoyance response. The present study, which assesses the effects of another type of transportation noise, that is, aircraft noise, is essential to generate a database for formulating Vietnamese and global noise policies. Since many residential areas are in the vicinity of main airports in Vietnam, aircraft noise, together with road traffic is a main noise source that is causing adverse effects on the quality of Vietnamese life. Therefore, this study investigates the impact of aircraft noise not only as a single but also as a combined source together with road traffic noise. The objectives of this study were (i) to propose a representative dose-response relationship for aircraft noise annoyance in Vietnam and (ii) to discuss the difference in annoyance among sites and between cities.

METHODS

## Survey sites

Ten residential areas were selected around Tan Son Nhat Airport, Vietnam's largest international airport with around 200 takeoffs and landings per day, locating inside a crowded residential area of Ho Chi Minh City (Figure 1). Nine sites were selected around Noi Bai Airport which is located 45 km from downtown Hanoi in the hub of many national arterial roads and industrial zones (Figure 2). The site selection was intended to reflect the aircraft noise exposure covering locations at various distances from and directions relative to the airport. Because this study was planned to investigate aircraft noise both as a single and as a combined source, all the sites except Sites 9 and 10 in Ho Chi Minh City and Site 6 in Hanoi were selected from residential areas that had roads passing through them. The houses facing the roads were selected for the combined noise survey, and those set back from the road were selected for single aircraft noise surveys (Figure 3).

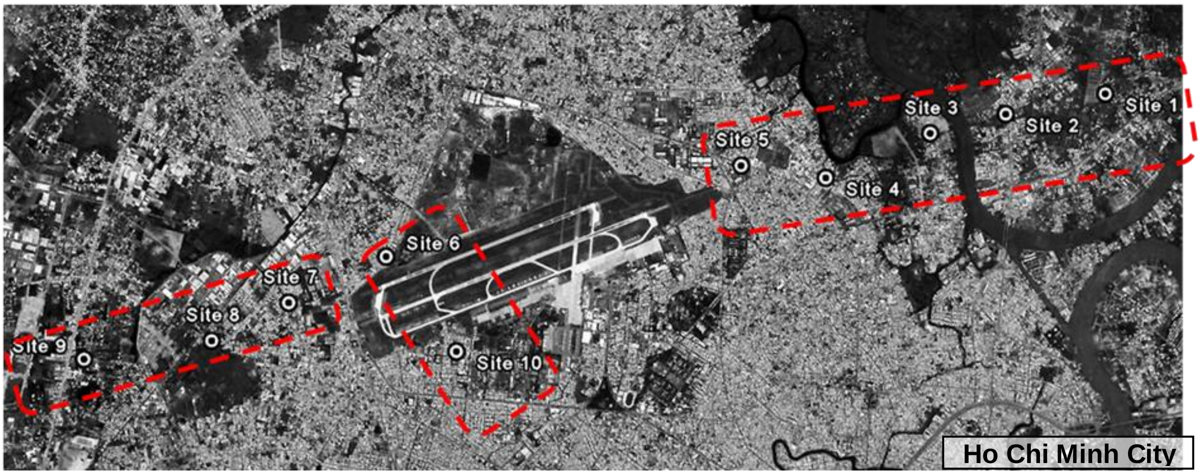


**Figure 1:** Map of survey sites in Ho Chi Minh City (Source: Google Earth)

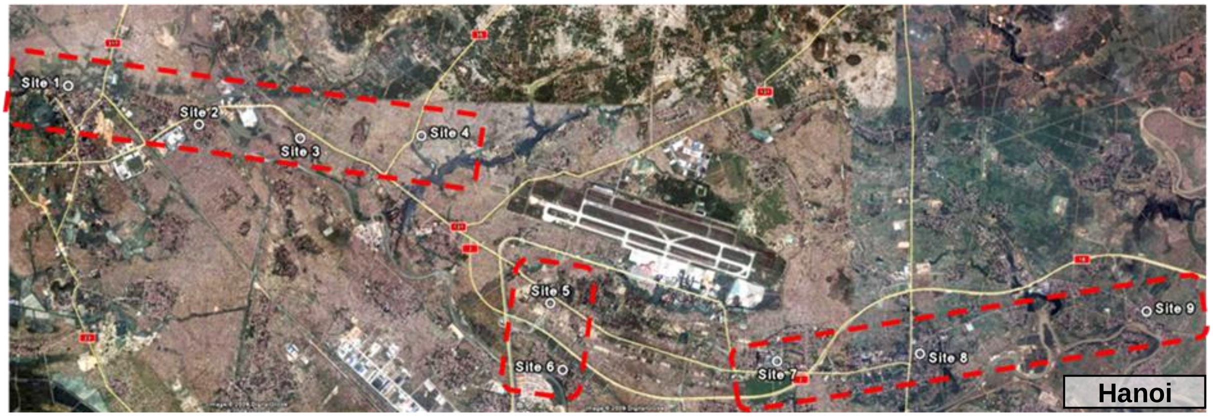


**Figure 2:** Map of survey sites in Hanoi (Source: Google Earth)

## Social surveys

Social surveys on community response to aircraft noise and combined noise from aircraft and road traffic were conducted around Tan Son Nhat Airport in Ho Chi Minh City from August to September 2008 and around Noi Bai Airport in Hanoi from August to September 2009. The surveys were conducted with face-to-face interviews during the daytime on weekends. Two types of questionnaires were used in this study — one for the single noise survey and the other for the combined noise survey. The questionnaire used in the combined noise survey, besides containing the same question as the single noise survey, had additional questions related to the annoyance caused by road traffic and combined noise. In the questionnaire, two scales — 5-point verbal and 11-point numeric — constructed according to the ICBEN (International Commission on Biological Effects of Noise) method were used to evaluate the respondents' noise annoyance (Yano & Ma 2004).

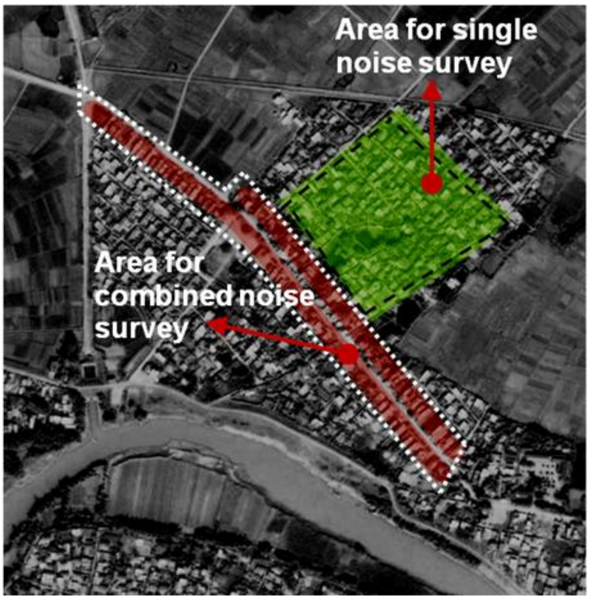


**Figure 3:** Example of areas for single and combined noise surveys at site 9 in Hanoi (Source: Google Earth)

## Noise measurements

Since there was a lack of available noise data in Vietnam, all noise databases for this study were compiled using field measurements. Noise measurements were performed in Ho Chi Minh City from September 22 to 28, 2008, and in Hanoi from September 10 to 17, 2009, by applying the same method in both cities. Aircraft noise exposure was measured every 1 s for seven successive days by using sound level meters (RION NL-21 and NL-22) in the areas of the single noise surveys. Flight numbers and conditions were obtained from the Airport Office at each airport.

The combined noise of aircraft and road traffic was measured every 1 s for 24 h in the areas covered in the combined noise surveys. Traffic volume was counted by panel-replaying the video recordings for 10 minutes every hour. Road traffic noise metrics were calculated by energy subtraction of aircraft from combined noise metrics.

# RESULTS AND DISCUSSION

## Results of social surveys

In total, 1,562 and 1,397 respondents participated in the surveys in Ho Chi Minh City and Hanoi, respectively. The response rates were very high in both cities: the average response rates were 87 % and 85 % in Ho Chi Minh City and Hanoi, respectively

(Table 1). Though there is a slight difference in ratio between the socio-demographic factors of the survey sites and the Vietnam population census, the respondents of all the surveys seem to represent the typical Vietnamese people.

**Table 1:** Outline of social surveys on community response to aircraft noise in Ho Chi Minh City and Hanoi

| | | Site ID | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| Ho Chi Minh City | | | | | | | | | | | | |
| Sample size | Single noise survey | 85 | 86 | 90 | 90 | 90 | 83 | 90 | 88 | 89 | 89 | 880 |
| | Combined noise survey | 90 | 66 | 88 | 89 | 90 | 85 | 87 | 87 | | | 682 |
| Response rate | | | | | | | | | | | | 87 % |
| Hanoi | | | | | | | | | | | | |
| Sample size | Single noise survey | 96 | 89 | 100 | 99 | 76 | 99 | 88 | 90 | 87 | | 824 |
| | Combined noise survey | 99 | 70 | 53 | 27 | 67 | | 81 | 77 | 99 | | 573 |
| Response rate | | | | | | | | | | | | 85 % |

## Traffic volumes and noise exposure

Figures 4 and 5 show the average number of flights in Ho Chi Minh City and Hanoi. It should be noted that between 9 and 10 p.m., more landings than takeoffs were observed in both cities. Tables 2–5 show the noise metrics calculated for aircraft and combined noise exposures at all the sites in both cities. The aircraft noise exposure ranged more widely in Ho Chi Minh City than in Hanoi. Aircraft and combined noise exposures were from 53 to 71 dB and 73 to 83 dB $L_{den}$ in Ho Chi Minh City and from 48 to 61 dB and 70 to 82 dB $L_{den}$ in Hanoi, respectively.

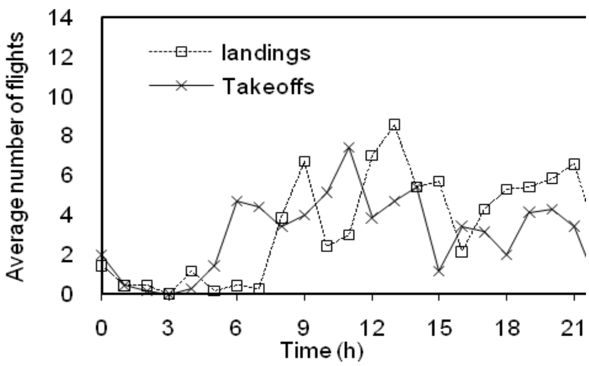


**Figure 4:** Number of flights in Ho Chi Minh City

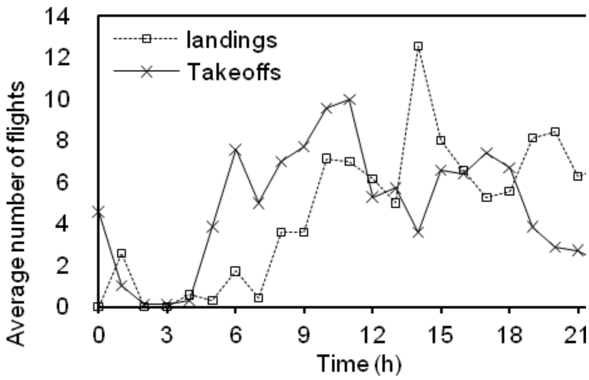


**Figure 5:** Number of flights in Hanoi

**Table 2:** Noise metrics calculated for aircraft noise exposure at all sites in Ho Chi Minh City

| Noise index (dB) | Site1 | Site2 | Site3 | Site4 | Site5 | Site6 | Site7 | Site8 | Site9 | Site10 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $L_{Aeq, day}$ (07:00~22:00) | 55.7 | 50.8 | 49.9 | 53.3 | 66.8 | 60 | 60.7 | 57.6 | 57 | 55.1 | 56.7 |
| $L_{Aeq, night}$ (22:00~07:00) | 51.5 | 44.7 | 48 | 49.2 | 61.7 | 55.8 | 57.7 | 54.8 | 54.2 | 52.6 | 53.0 |
| $L_{Aeq, evening}$ (19:00~22:00) | 54.9 | 47.3 | 48.2 | 52.7 | 67.7 | 60.9 | 61.7 | 58.4 | 57.8 | 55.2 | 56.5 |
| $L_{dn}$ | 58.9 | 52.8 | 54.8 | 56.7 | 69.5 | 63.2 | 64.8 | 61.8 | 61.2 | 59.5 | 60.3 |
| $L_{den}$ | 59.3 | 53.2 | 55.1 | 57.2 | 70.6 | 64.2 | 65.6 | 62.3 | 61.7 | 60 | 60.9 |
| $L_{Aeq,24h}$ | 54.2 | 49.4 | 49.4 | 52 | 65.8 | 59 | 59.8 | 56.8 | 56.2 | 54.4 | 55.7 |
| $L_{95}$ | 43.7 | 49.1 | 46.5 | 41 | 42 | 44.6 | 46.3 | 43.9 | 49.5 | 42.1 | 44.9 |
| % highly annoyed | 5.2 | 0.0 | 6.7 | 8.9 | 52.2 | 48.8 | 34.4 | 10.7 | 3.4 | 1.2 | 17.2 |

**Table 3:** Noise metrics calculated for aircraft noise exposure at all sites in Hanoi

| Noise index (dB) | Site1 | Site2 | Site3 | Site4 | Site5 | Site6 | Site7 | Site8 | Site9 | Average |
|---|---|---|---|---|---|---|---|---|---|---|
| $L_{Aeq, day}$ (07:00~22:00) | 51 | 52 | 58.3 | 54.1 | 45.6 | 46.2 | 54.1 | 57 | 48 | 51.8 |
| $L_{Aeq, night}$ (22:00~07:00) | 46.7 | 48.8 | 51.3 | 44.2 | 39.5 | 41.2 | 48.3 | 53.8 | 45.2 | 46.6 |
| $L_{Aeq, evening}$ (19:00~22:00) | 52 | 51.7 | 59.3 | 53.9 | 44.2 | 44.1 | 53.5 | 55.3 | 45.1 | 51.0 |
| $L_{dn}$ | 54 | 55.8 | 59.9 | 55.4 | 47.5 | 48.8 | 56.2 | 60.8 | 52.2 | 54.5 |
| $L_{den}$ | 54.7 | 56.2 | 60.9 | 56.3 | 48 | 49.2 | 56.8 | 61.1 | 52.4 | 55.1 |
| $L_{Aeq,24h}$ | 49.8 | 51 | 56.8 | 52.5 | 44.2 | 44.9 | 52.7 | 56.1 | 47.2 | 50.6 |
| $L_{95}$ | 39.7 | 45.3 | 47.9 | 38.8 | 41.7 | 47.1 | 40.7 | 42.7 | 43.6 | 43.1 |
| % highly annoyed | 6.5 | 11.5 | 57.0 | 68.4 | 18.4 | 4.1 | 8.3 | 20.0 | 4.7 | 22.1 |

**Table 4:** Noise metrics calculated for combined noise exposure at all sites in Ho Chi Minh City

| Noise metrics (dB) | Site1 | Site2 | Site3 | Site4 | Site5 | Site6 | Site7 | Site8 | Average |
|---|---|---|---|---|---|---|---|---|---|
| $L_{Aeq, day (07:00~22:00)}$ | 72.5 | 77.6 | 70.8 | 72.1 | 76.4 | 75.8 | 75.4 | 72.6 | 74.2 |
| $L_{Aeq, night (22:00~07:00)}$ | 67.5 | 75.5 | 64.9 | 66.2 | 73.7 | 70.5 | 69.5 | 70.5 | 69.8 |
| $L_{Aeq, evening}$ (19:00~22:00) | 70.8 | 76.3 | 69.6 | 73 | 75.9 | 75 | 75.6 | 72.8 | 73.6 |
| $L_{dn}$ | 75 | 82.2 | 72.8 | 74.1 | 80.6 | 78.2 | 77.4 | 77.3 | 77.2 |
| $L_{den}$ | 75.5 | 82.5 | 73.4 | 74.9 | 81 | 78.7 | 78.1 | 77.7 | 77.7 |
| $L_{Aeq,24h}$ | 71.2 | 76.9 | 69.4 | 70.7 | 75.6 | 74.5 | 74 | 71.9 | 73.0 |
| $L_{95}$ | 41.4 | 64.7 | 43.5 | 49.1 | 56.9 | 53.4 | 45.7 | 53.8 | 51.1 |
| % highly annoyed | 4.7 | 0.0 | 50.0 | 0.0 | 34.5 | 25.3 | 26.4 | 25.9 | 20.9 |

**Table 5:** Noise metrics calculated for combined noise exposure at all sites in Hanoi

| Noise metrics (dB) | Site1 | Site2 | Site3 | Site4 | Site5 | Site7 | Site8 | Site9 | Ave-rage |
|---|---|---|---|---|---|---|---|---|---|
| $L_{Aeq,\ day\ (07:00\sim22:00)}$ | 68.2 | 73.5 | 73.6 | 70.3 | 72.4 | 72.5 | 79.4 | 66.9 | 72.1 |
| $L_{Aeq,\ night\ (22:00\sim07:00)}$ | 61.2 | 71.8 | 71.8 | 65.3 | 67.1 | 67.1 | 72.5 | 62.8 | 67.5 |
| $L_{Aeq,\ evening}$ (19:00~22:00) | 66.2 | 72.7 | 72.8 | 69.5 | 68.2 | 68.3 | 80.4 | 62.1 | 70.0 |
| $L_{dn}$ | 69.6 | 78.5 | 78.5 | 72.8 | 74.8 | 74.8 | 80.9 | 70.1 | 75.0 |
| $L_{den}$ | 70.1 | 78.8 | 78.8 | 73.3 | 75 | 75.1 | 81.8 | 70.3 | 75.4 |
| $L_{Aeq,24h}$ | 66.6 | 73 | 73 | 69 | 71.1 | 71.1 | 77.9 | 65.8 | 70.9 |
| $L_{95}$ | 36.1 | 47.6 | 47.6 | 45.9 | 41.4 | 41.4 | 51.4 | 42.3 | 44.2 |
| % highly annoyed | 4.0 | 10.1 | 73.1 | 61.5 | 7.5 | 2.6 | 33.3 | 3.2 | 24.4 |

## Dose-response relationships

A logistic regression function was applied to plot the dose-response curves for aircraft noise annoyance. This was evaluated by the percentage of people highly annoyed in the single and combined noise surveys in Ho Chi Minh City and Hanoi; the day-evening-night average sound level ($L_{den}$) was chosen as the independent variable. Following the European Union (EU) position paper, in which the cut-off point for the highly annoyed was defined as the top 28 %, the authors defined the top three categories of the 11-point numeric scale (top 27 %) as highly annoyed.

Figure 6 shows the relationships for general annoyance in Ho Chi Minh City and Hanoi using synthesized data from the single and combined noise surveys. When the percentage of highly annoyed is higher than around 20 %, the two curves are almost parallel to each other with a noise level difference of approximately 8 dB. Hanoi's curves are higher than Ho Chi Minh City's. In other words, respondents in Hanoi were more annoyed by aircraft noise than those in Ho Chi Minh City at the same noise level.

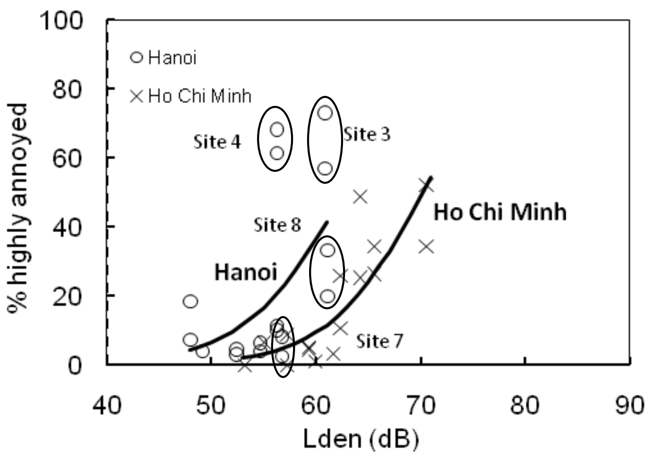


**Figure 6:** Dose-response relationships for general annoyance in Ho Chi Minh City and Hanoi using synthesized data from single and combined noise surveys

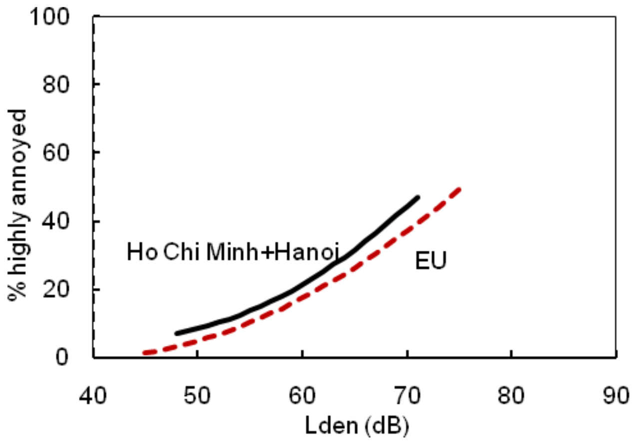


**Figure 7:** The synthesized curve of Ho Chi Minh City 2008 and Hanoi 2009 surveys in comparison with the EU's curve

Finally, the synthesized curve of Hanoi 2009 and Ho Chi Minh City 2008 surveys was plotted and compared with the EU's (Figure 7). At the same noise level, the percentage of highly annoyed respondents in Vietnam was slightly higher than those in the EU. In other words, there is 2 to 3 dB difference between the two curves at the same percentage of high annoyance.

## Difference in response among sites

In this section, the possible causes of high annoyance particularly at Sites 3 and 4 in Hanoi will be discussed through a comparison with Sites 7 and 8, which have the equivalent noise levels. Though respondents at Sites 3 and 8 were exposed to almost the same aircraft noise levels, 60.9 and 61.1 dB, respectively, those at Site 3 were found to be more highly annoyed by aircraft noise than those at Site 8 as shown in Table 3 and Figure 6. The same finding was also gained between Site 4 ($L_{den}$ = 56.3 dB) and Site 7 ($L_{den}$ = 56.8 dB). These results suggest that annoyance is affected not only by noise exposure levels but also by other factors.

It is noteworthy that Sites 3 and 4 and Sites 7 and 8 are, in pairs, located under the landing and takeoff paths, respectively. In the questionnaire survey, the respondents were asked to indicate how frequently they were disturbed by the airborne vibration from aircraft (Table 6). The results showed that, in the aircraft and combined noise surveys, the residents at Sites 3 and 4 were more frequently disturbed by the airborne vibration from aircrafts than those at Sites 7 and 8.

**Table 6:** Chi-square test of frequencies of respondents almost everyday and once or twice in a week disturbed by airborne vibration between sites under landing and take ff routes

| | Site 3 | Site 8 | Chi-square | P | Site 4 | Site 7 | Chi-square | P |
|---|---|---|---|---|---|---|---|---|
| Single survey | 55 | 45 | 1.9 | >.05 | 73 | 7 | 82.8 | <.001 |
| Combined survey | 64 | 43 | 5.4 | <.05 | 65 | 3 | 52.7 | <.001 |

In addition, the frequency of use of airplanes by the respondents at each site was assessed. As can be seen in the Table 7, the percentages of respondents who did not use airplanes at all were 89 % and 95 % in the aircraft noise areas of Sites 3 and 4, while these were only 50 % and 57 % at Sites 7 and 8, respectively. The differences are slightly smaller when considering combined noise areas at these sites.

**Table 7:** Chi-square test of frequencies of respondents who do not use airplanes at all between sites under landing and takeoff routes

| | Site 3 | Site 8 | Chi-square | P | Site 4 | Site 7 | Chi-square | P |
|---|---|---|---|---|---|---|---|---|
| Single survey | 89 | 57 | 24.0 | <.001 | 95 | 50 | 44.6 | <.001 |
| Combined survey | 76 | 57 | 4.9 | <.05 | 77 | 55 | 3.9 | <.05 |

Since sleep disturbance is also a main effect of noise on humans, the time at which respondents went to bed was investigated (Table 8). The results indicated that, with the exception of the aircraft noise area of Site 8, more respondents at Sites 3 and 4 went to bed between 9 and 10 p.m. than those at Sites 7 and 8. In addition, there are more landings than takeoffs observed during this period of the night (Figure 5). These facts might cause higher sleep disturbances at Sites 3 and 4, which were under the landing path of the aircraft, than at Site 8 at the same noise level. All the above reasons could be used to explain the higher annoyance found at Sites 3 and 4 than at the other sites.

**Table 8:** Chi-square test of frequencies of respondents who go to bed till 22:00 between sites under landing and takeoff routes

| | Site 3 | Site 8 | Chi-square | P | Site 4 | Site 7 | Chi-square | P |
|---|---|---|---|---|---|---|---|---|
| Single survey | 34 | 33 | 0.0 | >0.05 | 38 | 16 | 11.4 | <.001 |
| Combined survey | 21 | 15 | 1.9 | >0.05 | 48 | 7 | 23.2 | <.001 |

### Difference in response between cities

The results of previous studies indicated that individuals tended to judge the annoyance of an unwanted sound in terms of its relationship to background noise (Lim et al. 2008). The background noise level, in this study, is defined as the 95$^{th}$ percentile ($L_{95}$), as shown in Tables 2–5. It can be easily observed that the background noise levels at almost all sites of Ho Chi Minh City are higher than at those of Hanoi. While the average $L_{95}$ values in Hanoi are 43 dB and 44 dB for single and combined noise surveys, respectively, they are 45 and 51 dB in Ho Chi Minh City. The outstandingly larger traffic volume in Ho Chi Minh City might yield the higher background noise level there. It can be speculated that the noise of aircraft events in Hanoi when the background noise levels are lower might be generally more noticeable than in Ho Chi Minh City. Bivariate correlations were calculated between those noise metrics and each of three variables — individual annoyance score, average annoyance score, and percent highly annoyed. The results showed that $L_{95}$ was statistically significantly correlated at the 0.01 level with individual annoyance score evaluated by the respondents of all surveys. This finding emphasized the role of background noise level on the annoyance of respondents in Ho Chi Minh City and Hanoi.

## CONCLUSIONS

This study provided a broader knowledge on exposure situations as well as annoyance of aircraft noise in Vietnam. Aircraft and combined noise exposures ranged from 53 to 71 dB $L_{den}$ in Ho Chi Minh City and from 48 to 61 dB and 70 to 82 dB $L_{den}$ in Hanoi, respectively. The dose-response curve for aircraft noise for Vietnam was established and fitted onto the curve for the EU. It has been found that the curve for Vietnam was 2 to 3 dB higher than that for the EU at the same percentage of high annoyance.

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# Evaluation of urban space as a concept of soundscape

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## ABSTRACT

Although considerable effort has been made in community noise control, reducing the sound level does not necessarily lead to better acoustic comfort in urban spaces. Therefore, it is essential to consider the environmental conditions of urban environments and how they can attract people. Recent studies on the soundscape of urban space have shown that various kinds of contexts contribute to overall perception, and ISO/TC 43/SC 1/WG 54 has started to work on standardization of evaluation procedures. The present study deals with methodologies for evaluation and improvement of urban space as a concept of soundscape. Individual soundwalk methodology has been proposed for assessment of urban space and derivation of the design elements. In addition, sound masking methodology using water sounds has been investigated for improving soundscape perception.

## INTRODUCTION

Urban open spaces have contributed to the social and ecological effects of lifestyles and attitudes to nature and sustainability. The acoustical environment is a critical factor in the overall comfort of urban open spaces (Kang 2006). Therefore, considerable effort has been devoted to community noise control so as to investigate the relationship between the level of noise and the annoyance level of people. However, reducing the sound level does not always lead to improved acoustic comfort in urban spaces (de Ruiter 2004) and it is often not realistic to reduce community noises in open spaces. Therefore, the concept of soundscape has been adopted for the evaluation of the outdoor environment.

The initial concept of soundscape was proposed as an attempt to construct an analytical perspective that would describe the total acoustic environment over time and across cultures. Therefore, most soundscape studies concern the qualitative analysis of soundscapes. Schulte-Fortkamp & Fiebig (2006) adopted the Grounded Theory as a sociological approach, and Berglund & Nilsson (2006) proposed a tool for measuring soundscape quality by attribute profiling. However, the methods for evaluating a soundscape are different according to the purposes of the studies and the researchers, and thus it is difficult to directly compare the results of these studies. Even though many recent studies adopted the soundwalking methodology to identify the perception of an urban acoustic environment (Berglund & Nilsson 2006; Jeon et al. 2010a), the standardization of the procedures for assessing soundscapes are still being discussed in the ISO TC43 SC1 WG 54 (perceptual assessment of soundscape quality).

In the present study, the factors that influence soundscape perception in urban spaces were investigated through a social survey and classification of urban soundscapes was performed based on the assessment of contexts. Soundwalks were then performed for evaluation of urban soundscape. In particular, individual soundwalk was proposed to investigate the details of perceptual difference of subjects. For the improvement of urban soundscape, water sounds were introduced, and the effects of water sound on urban soundscape were investigated through auditory experiments..

## CONTEXTS AFFECTING SOUNDSCAPE PERCEPTION IN URBAN SPACES

### Social survey

Social surveys were performed in Seoul in order to evaluate the perception of the urban soundscape based on its context. Ten sites were chosen based on the fact that each site had a different urban environment with various combinations of buildings, road traffic, water features, and trees. Table 1 shows the main functions and sound sources for each site.

**Table 1:** Sites with sound sources

| Site | Main function | Sound sources | Site | Main function | Sound sources |
|---|---|---|---|---|---|
| 1 | Commercial, office | Traffic, footsteps, music from buildings, surrounding speech | 6 | Office, cultural (historic building) | Traffic, footsteps, speech |
| 2 | Commercial, office | Traffic, footsteps, construction, music from buildings, surrounding speech | 7 | Relaxation, office | Traffic, footsteps, speech, water (stream) |
| 3 | Square, office | Traffic, water (fountain), construction, children | 8 | Commercial, office | Traffic, footsteps, water (stream), music from buildings |
| 4 | Square, office, cultural | Traffic, water (fountain), surrounding speech | 9 | Relaxation | Wind, birds, children, Traffic |
| 5 | Commercial | Traffic, footsteps, music from buildings | 10 | Relaxation, recreation | Wind, birds, speech, traffic |

### Quantitative analysis

Sound pressure levels measured at each site were strongly correlated with acoustic comfort ($r$=-0.85, $p<0.01$), whereas the correlation between sound pressure level and overall impression was not statistically significant ($r$=-0.36, $p=0.31$). The overall impression of site 4 was the highest even though its sound level was the highest; this indicates that the perception of an urban soundscape is not predominantly dependent on sound pressure level and is affected by other elements of the context. Site 9 (city park) was evaluated as the best urban space with regard to all tested contexts, whereas site 2 (with heavy road traffic and high-rise buildings) was chosen as the worst urban space. Correlation coefficients between overall impressions and the contextual evaluation results were calculated. Daylighting and fragrances and odors were significantly correlated with overall impression (0.68 and 0.65; $p<0.05$), whereas acoustic comfort, visual image, and reverberance were not (0.34, 0.52, and 0.61; $p>0.05$)

## Classification of urban soundscapes

Classification of urban soundscapes was carried out through hierarchical cluster analysis on the basis of the evaluation results of the contexts, as shown in Figure 1. Based on the results, three groups (A-C) were created. Group A consisted of various types of urban spaces, including urban squares (sites 3 and 4), streets with light traffic (sites 5 and 6), a city stream (site 7), and a city park (site 10). The perceptions of the urban spaces included in Group A were not significantly different in terms of contexts. Group B contained two store-filled streets with heavy traffic (sites 1 and 2) and a pedestrian road with heavy traffic (site 8). Site 8 was categorized into Group B because sound from the small stream was rarely heard; hence, road traffic noise was likely to be dominant as it was at sites 1 and 2. Site 9 (green space) was categorized into Group C and was distinguished from the other urban soundscapes as receiving the highest subjective responses with regard to all of the contexts.

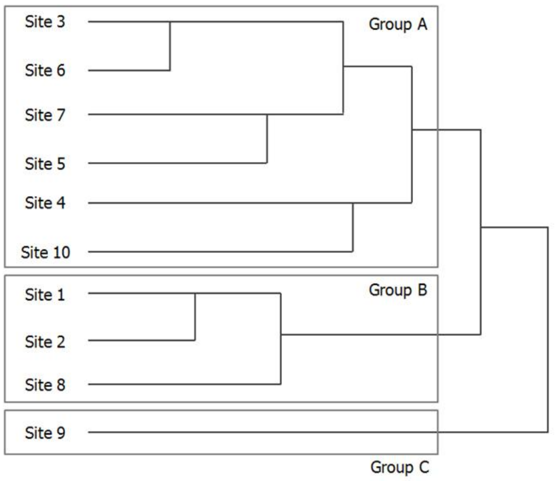


**Figure 1:** Classification of urban soundscapes, presented as a tree diagram (dendrogram) from a cluster analysis (the rectangles indicate Groups A-C)

Correlation coefficients between the overall impressions and the evaluation results of the contexts for Groups A-C are listed in Table 2. In the case of Group A, acoustic comfort, daylighting, and visual image were highly correlated with overall impression. Acoustic comfort and daylighting were also highly correlated with overall impression in the case of Group B, but the overall impression for Group C was correlated only with daylighting.

**Table 2:** Correlation coefficients between overall impression and contexts (*p<0.05, **p<0.01)

| | Acoustic comfort | Visual image | Daylighting | Fragrances and odors | Reverberance |
|---|---|---|---|---|---|
| Group A | 0.37** | 0.55** | 0.36** | 0.18* | 0.22** |
| Group B | 0.44** | 0.21* | 0.31** | 0.16 | 0.14 |
| Group C | 0.35 | 0.32 | 0.54** | -0.003 | 0.36 |

EVALUATION OF URBAN SPACES THROUGH SOUNDWALK

## Group soundwalk

Twelve sites in Sydney were selected by considering various elements that contribute to the urban environment, such as buildings, roads, squares, and water features. Figure 2 shows the two chosen soundwalk routes, A and B. Sites 1, 6, and 12 were urban parks, and sites 2 and 9-12 were tourist attractions near the waterfront. Sites 3-5 and 8 were commercial and office districts that were exposed to heavy traffic. The soundwalk was carried out twice along two routes. Route A began at site 1 and ended at site 6, while route B passed from site 7 to site 12. Eleven participants comprised of domestic and foreign acoustics experts evaluated the urban soundscapes through questionnaires during the one-hour walks. The soundwalks were conducted in silence, and the participants were asked to concentrate on what they heard and observed about the urban environment. The questionnaire used in the soundwalk was almost the same as that used in the social survey, except for the qualitative analysis. In the soundwalk, participants were asked to describe their impressions and personal opinions.

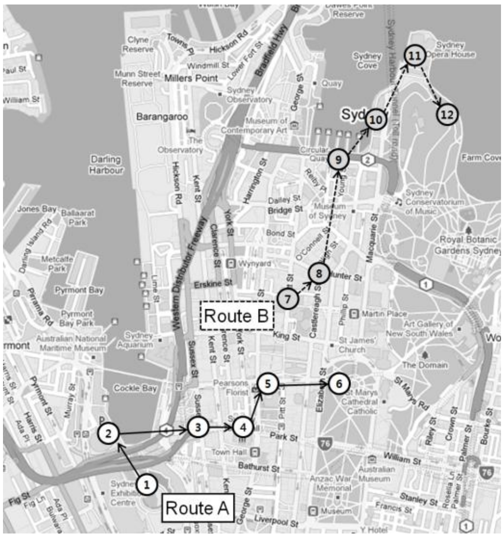


**Figure 2:** Soundwalk routes and evaluation sites in Sydney (source: Google Maps)

Grounded theory was used for textual analysis of the descriptions. Throughout the coding processes, perceptions of soundscapes were categorized into four themes, as shown in Table 3: 1) acoustic environment, 2) physical context, 3) psychological context, and 4) responses and outcomes.

**Table 3:** Categories extracted from the descriptions

| Theme | Category | Subcategories | Keywords |
|---|---|---|---|
| Acoustic environment | Acoustic | Natural | Bird, wind, water sounds |
| | | Artificial | Construction, traffic, music |
| | | Soundmark | Identified, dominant |
| | | Temporal features | Stationary, nonstationary |
| Physical contexts | Spatial aspects | Openness | Open, closed |
| | | Density | High / low density |
| | Visual image | Color | Green, blue, etc. |
| | | Brightness | Dim, bright |
| | | Green space | Park, grass, trees, woods |
| | | Waterfront | River, sea, stream, fountain |
| | | Landmark | Towers, skyscrapers |
| | Olfactory | Unpleasant odor | Smoke |
| | | Pleasant odor | Water, tree, clean air |
| Psychological contexts | Individual | Sensitivity (to) | Noise, odor |
| | | Experience | Experience, familiarity |
| | Socio-cultural | Urban images | Image of city, attraction |
| Responses and outcomes | Responses | Positive | Favorable responses |
| | | Negative | Unfavorable responses |
| | | Neutral | Mixed responses |
| | Outcomes | Stayed | Wanted to stay |
| | | Left | Did not want to stay |
| | | Improve | Improvement of conditions |

## Individual soundwalk

Individual soundwalk methodology was proposed in order to investigate the details of subjects‘ perceptions. Major difference between group and individual soundwalk is a method for selection of evaluation locations. In case of group soundwalk, locations are selected by researchers, whereas those were chosen by individuals who participated in the individual soundwalks. During individual soundwalk, the subjects were given a map that indicated the area for soundwalk. They were then required to walk around that area for about an hour, stop walking and fill in the questionnaire at any locations where they noticed any positive or negative characteristics of urban environment. They also recorded environmental noise and took photographs of urban spaces simultaneously.

The urban soundscape was evaluated using a questionnaire to assess the acoustic environment and landscape, along with general questions about the participants themselves. The questions were arranged in two basic sections. The first section sought to obtain the overall impression and preference of sound source and physical conditions of the urban soundscape based on the box diagram discussed in ISO WG54. Acoustic comfort was chosen as the evaluation variable of the sound field, and visual image, daylighting, fragrances and odors, and openness were also selected for the assessment of physical conditions. These conditions were evaluated using an 11-point numerical scale (with 0 signifying not at all and 10 signifying extremely). In the second section, subjects were asked to describe soundmarks (analogous to landmarks) of the site.

Individual soundwalk was carried out in Seoul and 30 people (15 architects and 15 acousticians) were took part in. Locations that subjects stopped for the evaluation of urban soundscape were plotted in Figure 3(a). Contrary to the group soundwalk which limits the number of evaluation locations, numerous locations were selected in the individual soundwalk. This indicates that the impressions from urban spaces can be various among the subjects. As shown in Figure 3(b) the locations were grouped into 16 spots considering the number of subjects and similarity of perceptions. Blue or orange circles in different size indicate the selected numbers of locations where overall impressions were either positive or negative, respectively. The reasons why the overall impressions were different will be investigated considering the perceptions on contexts of urban soundscape.

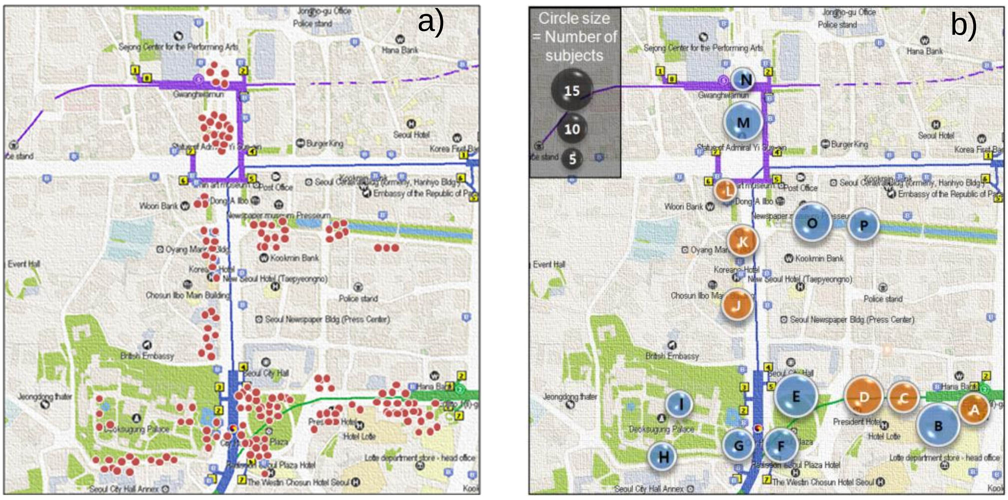


**Figure 3:** The locations selected by subject during individual soundwalks

## ENHANCEMENT OF URBAN SOUNDSCAPE USING WATER SOUNDS

### Perceptual difference of the water sound level

Auditory experiment was carried out to determine the perceptual difference in the S/N ratio between water sounds and road traffic noise. An auditory experiment with two-alternative force choice (2AFC) method was conducted to investigate the just-noticeable difference (JND) of the stimuli. The sound pressure levels (A-weighted equivalent sound pressure levels for 10 s, $L_{Aeq,10s}$) of road traffic noise were fixed at 55 or 75 dBA. When the SPL of road traffic noise was fixed at 55 or 75 dBA, the SPLs ($L_{Aeq,10s}$) of water sounds varied from 49 to 61 dBA and 69 to 81 dBA, respectively, with a step of 1 dB. During experiments, subjects were asked to select the louder stimulus of each pair. Twenty subjects, 11 males and 9 females between the ages of 22- and 32-years, participated in this experiment.

Figure 4 represents the results of auditory experiment in which road traffic noise levels were fixed at 55 and 75 dBA. The regression lines obtained from probit analysis were plotted in Figure 4. More than 75 % of the subjects correctly identified differences in S/N ratio of approximately 3 dB when road traffic noises were presented at 55 and at 75 dBA. The response in the left half (SPL of the water sounds is smaller than that of the road traffic noise) showed the similar tendency to the response in the right half.

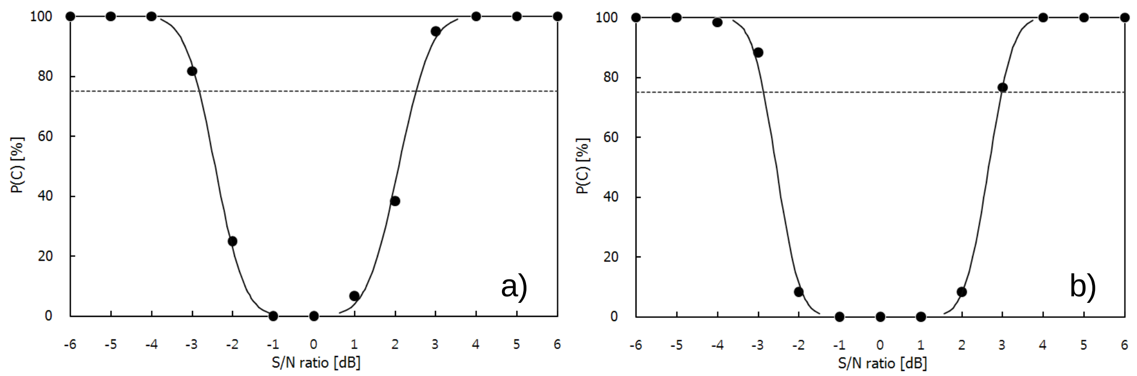


**Figure 4:** The results of experiment: (a) road traffic noise of 55 dBA and (b) road traffic noise of 75 dBA.

## Proper level difference between water sounds and road traffic noise

The road traffic noise levels were fixed at 55 and 75 dBA ($L_{Aeq,20s}$) while the SPLs ($L_{Aeq,20s}$)of the water sounds were varied, for a total of five S/N ratios from -6 to +6 with a step of 3 dBA. Sound pressure levels of combined signal consisting of road traffic noises and the water sounds ranged from 55.9 to 61.9 dBA and from 75.9 to 81.9 dBA, respectively when the road traffic noise levels were fixed at 55 and 75 dBA. In this experiment, five water sounds, F (fountain), S1 (stream), S2 (stream), FW (falling water), and W (water fall) were presented as stimuli. Paired comparison tests were performed for stimuli (road traffic noise with water sounds) with changes in the S/N ratio. The subjects were asked to respond to the following question, "*Which stimulus would be more preferable if you were exposed to it in an urban space?"*

The results of this experiment are plotted in Fig. 5. Fig. 5 (a) represents the results in which road traffic noise was presented at 55 dBA, and Fig. 5 (b) indicates the results in which road traffic noise was presented at 75 dBA. As shown in the Fig. 5 (a), water sounds presented at a S/N ratio of -3 dB were most preferred for all five cases with different S/N ratios when the road traffic noise level was fixed at 55 dBA. A similar pattern was observed when the SPL of road traffic noise was set at 75 dBA. Subjects preferred all five water sound stimuli when the SPL of water sounds was 3 dB lower than that of the road traffic noise. S1 and FW were the most highly preferred water sounds, and S1 showed positive scale values for every case with changes of S/N ratio. Unlike S1, the scale values for F and W were negative and showed almost constant values for every case. This indicates that the sounds of the fountain and waterfall were not effective for masking road traffic noise presented at 75 dBA.

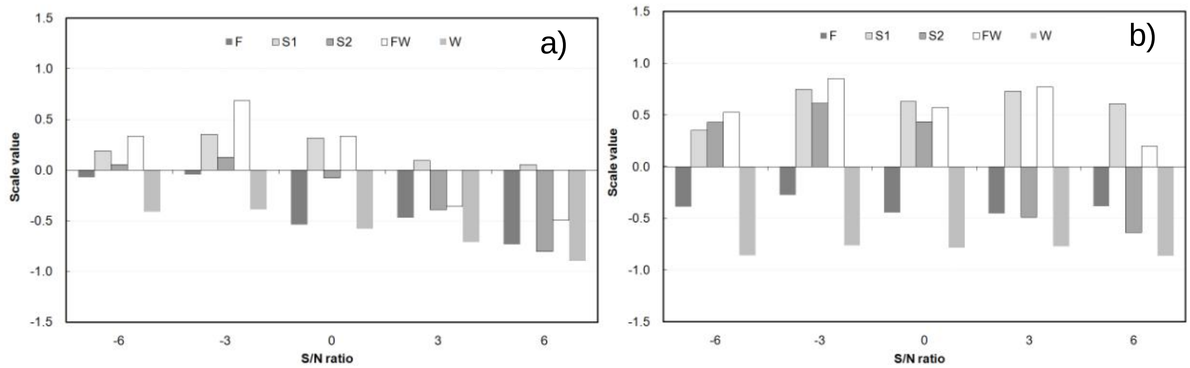


**Figure 5:** The results of experiment: (a) road traffic noise of 55 dBA and (b) road traffic noise of 75 dBA

**Effect of audio-visual interactions**

The preference test was performed to investigate, in terms of preference, the effect of water sounds on the masking of road traffic noise. In the experiments, two conditions were considered: 1) an audio-only condition and 2) a combined audio-visual condition, where, images were provided along with the sound stimuli during the experiment. A total of 14 experimental sounds were constructed: road traffic noise only and road traffic noise combined with 13 water sounds. The experiments were conducted twice with two presentation levels of road traffic noise: 55 and 75 dBA. The signal-to-noise ratios (SNR) between the water sounds and road traffic noise were set to -3 dBA so that the levels of the water sounds were 52 and 72 dBA (Jeon et al. 2010b).

The results of the preference test when the road traffic noise level was fixed at 55 dBA are shown in Figure 6(a). Preference scores obtained from the audio-only session are shown in white columns and the results from the audio-visual session are given in gray columns. All of the stimuli combining road traffic noise and water sounds were judged to be significantly better, in terms of preference ($p<0.01$), than road traffic noise alone. It was also found that improvements in the preference scores were affected by the types of water sounds. Experimental results obtained with road traffic noise of 75 dBA are shown in Figure 6(b). Similar to that at 55 dBA, water sounds led to significantly better ratings of preference ($p<0.01$).

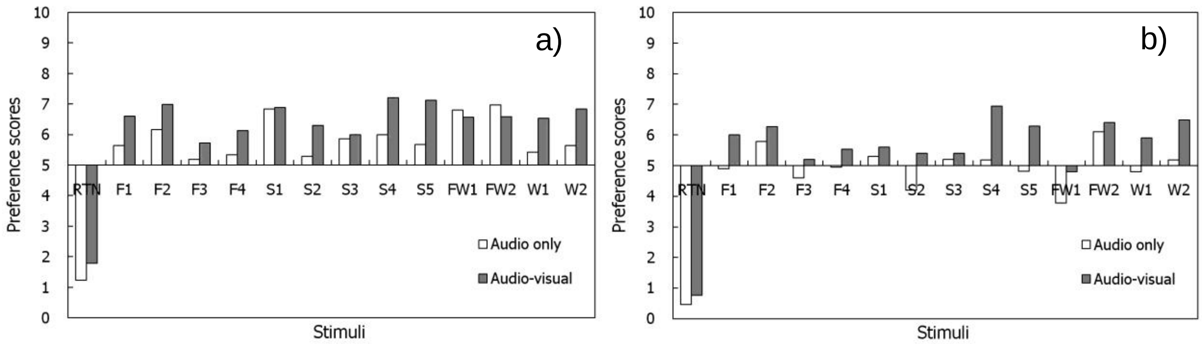


**Figure 6:** Experimental results for water sounds combined with road traffic noise at Leq 55 (a) and 75 dBA (b)

CONCLUSIONS

In this study, urban soundscapes were evaluated using a social survey in order to investigate the effects of contexts on soundscape perception. In the social survey, urban soundscapes were classified into Groups A-C based on the context evaluation results. In addition, urban soundscapes were assessed by soundwalks. From group soundwalks, it was found that spatial impressions such as openness and density of urban spaces influenced soundscape perception. The results of individual soundwalk also showed that locations that the subjects perceived positive or negative impressions were different. Furthermore, the results of auditory experiment represented that the perceptual difference of the water sound level was around 3 dB with noises from road traffic in the background, the water sound, which had 3 dB less sound pressure level, was evaluated as preferable when the levels of road traffic noise were 55 or 75 dBA, and preference scores for the urban soundscape were affected by the acoustical characteristics of water sounds and visual images of water features.

## ACKNOWLEDGMENTS

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# Effects of airplane and helicopter noise on people living around a small airport in Sapporo, Japan

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## INTRODUCTION

Many field studies on aircraft noise have been conducted, but there have not been sufficient studies on noise around small airports. Rylander & Bjorkman (1997) carried out surveys in eight areas near three small and medium sized airports and concluded that noise levels are not of significant concern when the number of events is low. They cited a previous study covering similar sized airports in the US, which too found that the use of equal energy levels to express the noise exposure gave fewer precise relationships (Connor & Patterson 1976).

Okadama airport is a small airport in Sapporo, which lies in a residential area. It is used by commercial airplanes that connect local airports in Hokkaido prefecture and by helicopters of the Japan Self-Defense Forces. There are no jet runways, and night-time departures and arrivals are prohibited.

A survey was carried out around Okadama airport in 2007 to investigate the effects of aircraft noise on the local population, followed by a supplementary survey in 2008.

## OUTLINE OF THE SURVEY

Okadama airport is located in north-east part of Sapporo. Five sites were selected around the airport as representative of the aircraft noise at various distances and directions from the airport. All the sites selected were such that they did not directly face any arterial road, so as to avoid the effects of road traffic noise. A social survey was carried out around Okadama airport from September to October 2007 and a supplementary survey from August to September 2008 (Table 1). The survey consisted of a questionnaire and noise measurements. The distribution-postal collection method was used in 2007 and the postal method was used in 2008. The questionnaire was delivered to the people living in detached houses as a general survey on the living environment. The content of the questionnaire is shown in Table 2. The respondents were selected on a one-person-per-family basis under the criteria that they were over 18 years of age, and that their birthday was close to September 1. The key questions concerned annoyance, activity disturbance, and related effects caused by aircraft. The questions were answered on a five-point verbal scale and an 11-point numeric scale, shown in Table 3. The modifiers in the Japanese language for the verbal scales were determined in a joint study conducted by the International Commission on Biological Effects of Noise (Fields et al. 2001). The English language modifiers that were determined in the same manner are also shown in Table 3 for comparison. The total number of respondents was 383, and the response rate was 44.6 %. Analysis of the data showed that the extent of annoyance was rather high in spite of the low noise exposure levels. The authors thought that one reason was the usage of the term "aircraft noise" in the questionnaire. The fact led us to perform a supplementary survey in 2008, in which the terms "airplane noise," "helicopter noise," and "combined noise" were used instead of "aircraft noise." In this survey, 291 responses were obtained, and the response rate was 76.0 %. Figure 1 shows the relative response rates to questions concerning personal and housing factors. The proportions are almost the same in gender and in length of residence, whereas in age, over fifty occupies the high proportion. Most of the respondents live in their own house constructed of wood with two layers of window glass.

**Table 1:** Outline of the surveys

| | Survey in 2007 | Supplementary survey in 2008 |
|---|---|---|
| Area | Sapporo | |
| Housing type | Detached houses | |
| Survey site | Five sites around Okadama airport | |
| Method | Distribution-postal collection | Postal |
| Questionnaire term | September to October 2007 | August to September 2008 |
| Measurement term | October 2007 | |
| Sample size | 859 | 383 (same respondents as in 2007) |
| Respondent | 383 | 291 |
| Response rate (%) | 44.6 | 76.0 |
| Number of scheduled airplane flight | 17 (Departure from 7:40 to 17:35)<br>17 (Arrival from 9:25 to 18:50) | |
| $L_{Aeq}$,24h (dB)* | 28-40(airplane), 38-49(helicopter), 39-50(combined) | |
| Observed noise event* | 7.3-14.3(airplane), 13.8-40.5(helicopter) | |

*average of four-day data

**Table 2:** Questionnaire items of the surveys

| Survey in 2007 | | |
|---|---|---|
| Q1 - Q8 | Housing factors | House type; length of residence; main structure; number of glass layers in living room and bedroom windows; direction of doors and windows; housing performance |
| Q9 - Q12 | Residential environment | Quality of residential environment; satisfaction with living area |
| Q13 – Q17 | Annoyance | Road traffic noise; <u>aircraft noise;</u> railway noise; exhaust gas; industrial noise; bad smell; industrial air pollution; neighborhood noise; electromagnetic waves; frequency of aircraft noise annoyance; annoyance at specific times and seasons, etc. |
| Q18 | <u>Activity disturbance and related effects caused by aircraft</u> | Listening, sleeping disturbance; disturbance while resting, talking, gardening; house vibration due to aerial vibration; startle; fear of accident, etc. |
| Q19 – Q28 | Sensitivities, attitudes, etc. | Sleeping with open window in certain seasons; time of going to bed and getting up on weekends and weekdays; sleeping condition; sensitivity to environmental factors; attitudes to the use of transportation vehicles; using frequency; comments on safety, etc. |
| Q29 - Q33 | Socio-demographic variables | Occupation; length of period to stay at home; number of family members; age; gender |
| Supplementary survey in 2008 | | |
| Q1 - Q6 | Annoyance | <u>Airplane noise; helicopter noise; combined noise;</u> frequency of helicopter noise annoyance; annoyance at specific times or seasons, etc. |
| Q7, Q8 | <u>Activity disturbance and related effects caused by helicopter</u> | Listening, sleeping disturbance; disturbance while resting, talking, gardening; house vibration due to aerial vibration; startle; fear of accident, etc. |

After the questionnaires were completed, noise measurements were performed on each site, in a garden or open space next to the house. Noise exposure levels were recorded every 1 second for five successive days using a sound level meter (RION NL-22). Data could not be obtained on the last day because of heavy rain; therefore, four-day data were adopted for calculating the noise index values. Airplane and helicopter noise events were identified from the waveforms, as shown in Figure 2.

**Table 3:** Rating scale

(a) Verbal scale

| Category | Japanese | English |
|---|---|---|
| 5 | hijoni | extremely |
| 4 | daibu | very |
| 3 | tasho | moderately |
| 2 | sorehodo…nai | slightly |
| 1 | mattaku…nai | not at all |

(b) Numeric scale

0 1 2 3 4 5 6 7 8 9 10

Mattaku …nai — Hijoni

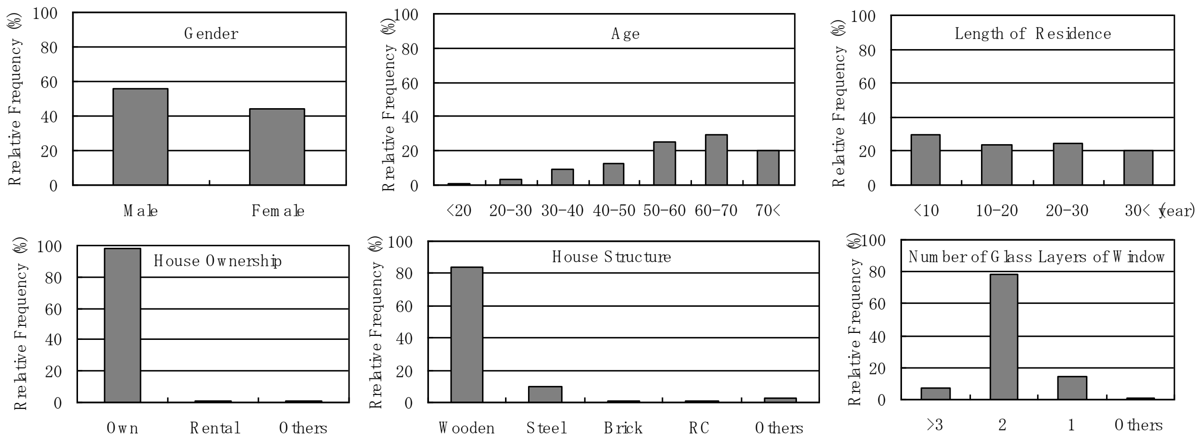



**Figure 1:** Personal and housing factors of respondents

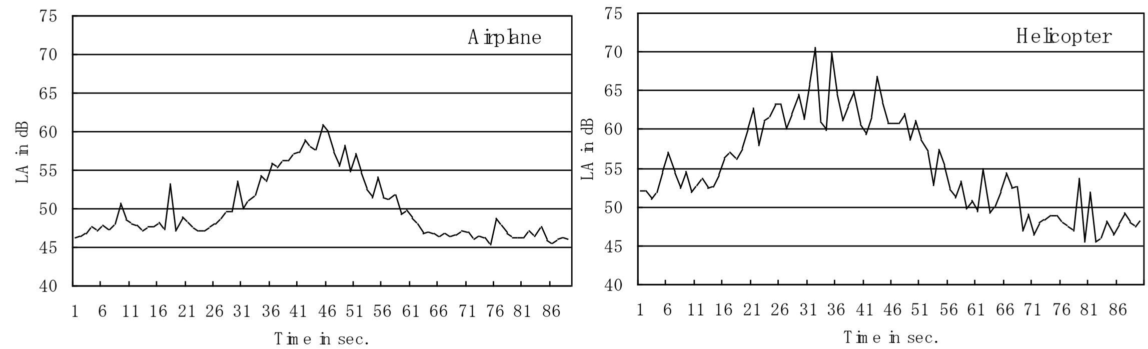



**Figure 2:** Typical waveforms of airplane and helicopter

**Table 4:** Noise exposure level, $L_{Aeq}$,24h in dB

| Site | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Airplane | 36 | 31 | 39 | 28 | 40 |
| Helicopter | 47 | 38 | 48 | 43 | 49 |
| Combined | 47 | 39 | 48 | 43 | 50 |

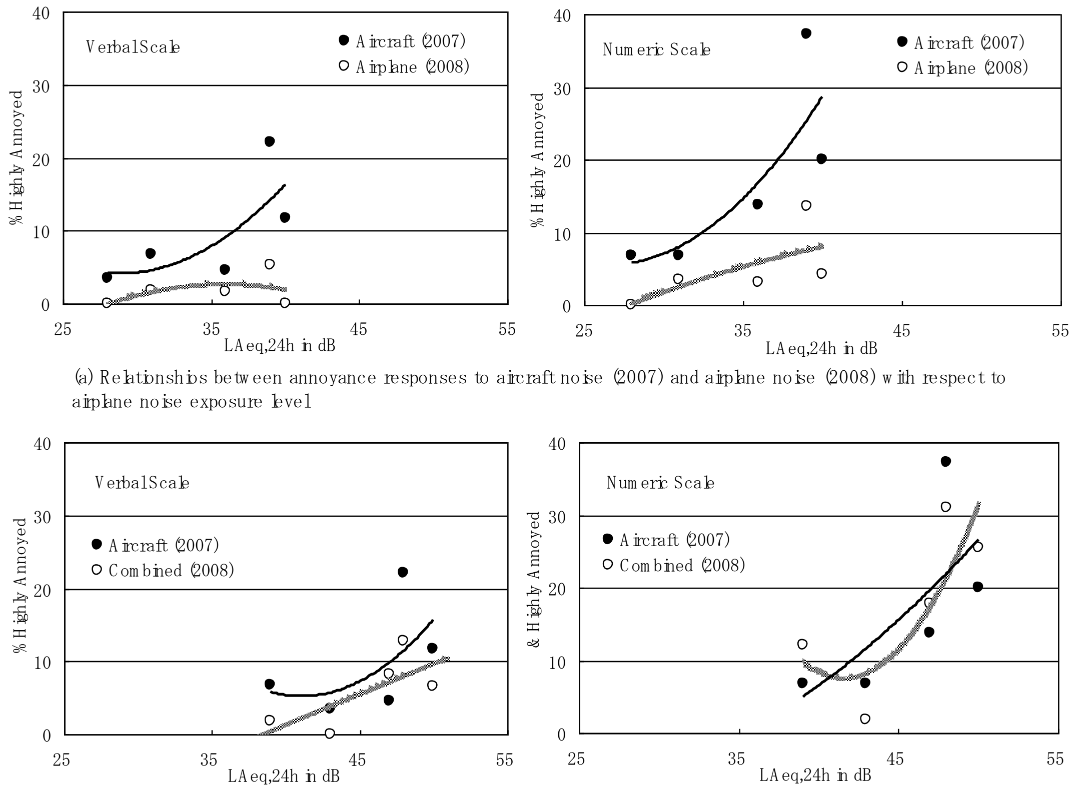
$L_{Aeq}$,24h values in Table 4 were calculated from those noise events. It was found that helicopters are the dominant noise source around Okadama airport.

## RESULTS AND DISCUSSION

### Dose-response relationships

Figure 3 (a) compares the annoyance responses to “aircraft noise (2007)” with the responses to “airplane noise (2008)” on the airplane noise exposure levels, and (b) compares with “combined noise (2008)” on the combined noise exposure levels. The percentage of highly annoyed respondents is defined here as the rate of the number of people who responded to the top category on the verbal scale and the top three categories on the numeric scale. For most Japanese people, the term “aircraft” has the same meaning as “airplane” when used in daily conversation. It is seen that both lines are close together in (b). This indicates that people seem to respond to the annoyance of both airplane and helicopter noises, even if they are asked about the annoyance due to “aircraft” noise.

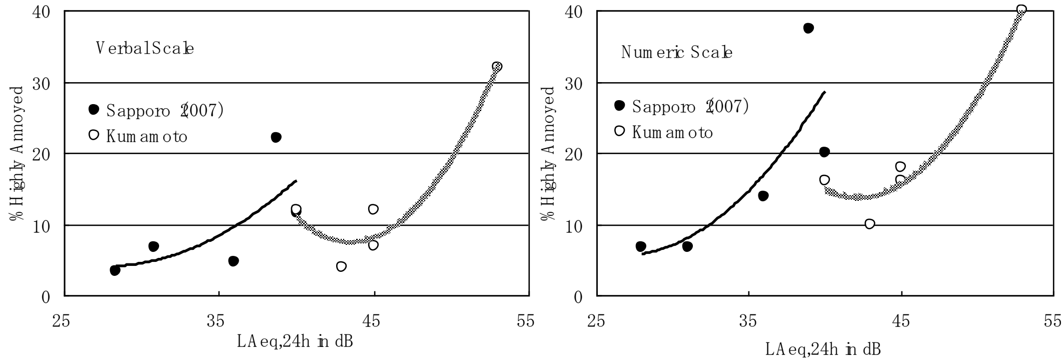
Figure 4 (a) compares the annoyance responses to aircraft noise (2007) with those obtained from the survey around Kumamoto airport (Henmi et al. 2007) on the airplane noise exposure levels, and (b) compares the combined noise exposure levels. It is seen that both lines are close together in (b). This also indicates that people seem to respond to the annoyance of both airplane and helicopter noises, even if they are asked about “aircraft” noise annoyance.



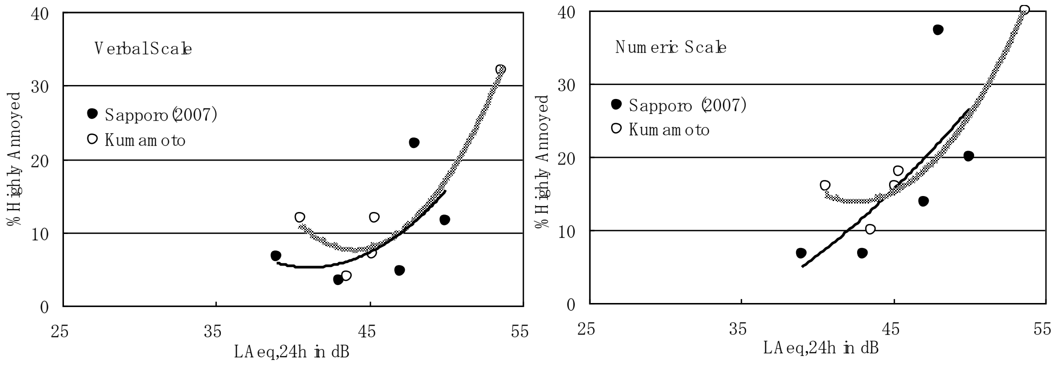

(a) Relationships between annoyance responses to aircraft noise (2007) and airplane noise (2008) with respect to airplane noise exposure level

(b) relationships between annoyance responses to aircraft noise (2007) and combined noise (2008) with respect to combined noise exposure level

**Figure 3:** Relationships between annoyance responses in the 2007 and 2008 surveys




(a) Relationships between annoyance responses to aircraft noise around two airports with respect to airplane noise exposure level




(b) Relationships between annoyance responses to aircraft noise around two airports with respect to combined noise exposure level

**Figure 4:** Relationships between annoyance responses around Sapporo Okadama and Kumamoto airports

Figure 5 shows the relationship between the annoyance responses to combined noise and airplane noise compared with Miedema's curve (Miedema & Vos 1998). This is evaluated by the percentage of highly annoyed respondents and the day-night average sound level ($L_{dn}$). Following Miedema's paper, in which the cut-off point for the highly annoyed was defined as the top 28 %, the authors prorate the relevant data in both scales to be 28 %. The data of the present study exceed Miedema's line. It suggests the existence of some factors, which do not reduce the annoyance at the low noise exposure levels. Fidell & Silvati (2004) proposed a modified curve in which the extent of annoyance is higher at the low noise exposure levels. Rylander & Bjorkman (1997) also suggested that noise levels are less important when the number of events is low. The results obtained here might be explained by a comparison with those studies.

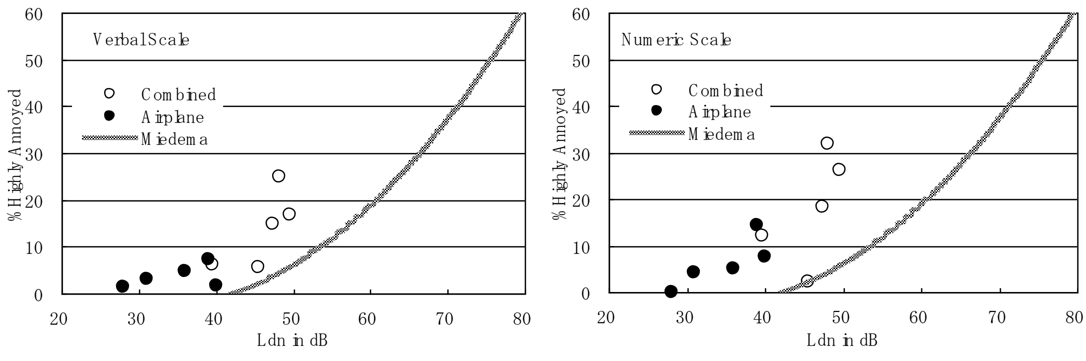



**Figure 5:** Comparison of annoyance responses with Miedema's curve

**Structural equation modeling**

Considering the causal relations among the variables, covariance structure analysis was performed on the aircraft noise annoyance. Covariance structure analysis is one of the general methods of investigating the hypothetical causal linkages between variables, and has been successfully used in noise evaluation studies by Morihara et al. (2004), Lam et al. (2009), and others.

The structural equation model was constructed using the data from the 2007 survey, based on knowledge from previous studies and the values of the fit indices.

To construct the causal relationships between noise annoyance and other factors such as noise levels, personal sensitivity, etc., the following hypotheses were made:

1) Aircraft noise exposure level causes not only noise annoyance but also daily activity disturbances such as listening disturbance.
2) The length of residence in the area affects the annoyance/activity disturbances.
3) Personal sensitivity to noise/vibration affects the annoyance/activity disturbances.
4) Activity disturbances increase the aversion to noise source.
5) Satisfaction with the living area/house affects the level of aversion to the noise source.
6) Aircraft flight causes fear of accident/crash and startle.
7) Aversion to the noise source comprises of noise annoyance and house vibration annoyance due to aerial vibration.

Fit indices were used for judging whether the models could express the character of the data well. The fit indices used in this study are GFI (Goodness of Fit Index), CFI (Comparative Fit Index), and RMSEA (Root Mean Square Error of Approximation). The model is good if the value of GFI or CFI is over 0.9 (close to 1) or if the value of RMSEA is under 0.05 (close to 0). If the RMSEA ranges from 0.05 to 0.1, it is considered to be in the gray zone.

Covariance structure analysis can build models using a latent variable such as "listening disturbance," which is treated as a comprehensive concept constituting the three observed variables of listening disturbance.

Figure 6 shows a primary structural equation model of annoyance caused by aircraft noise. The variables in the squares are the observed variables and those in the ovals are the latent variables. The arrows show the causal relations between the variables. Error variables are shown in circles.

Among the paths in this model, some were statistically proved to be not significant. The first revised model was made by excluding non-significant paths; consequently, the sleeping disturbance variables were deleted. In the same manner, the second revised model was made by excluding the non-significant paths of the first revised model and the variables for activity disturbance in the garden were deleted. Finally, the path with the largest probability value ($p = 0.035$), from the residential environment to aversion to noise source, was deleted to increase the fit indices' values. The final revised model is shown in Figure 7, and the values of the fit indices are shown in Table 5. Considering the values of the fit indices, the model is not exceptionally good, but it is acceptable. The standardized total effects of the independent variables on aircraft noise annoyance were calculated by the maximum likelihood method, and summarized in Figure 8. “Standardized total effects” means the degree of the contribution of each variable to aircraft noise annoyance. Aircraft noise annoyance is mainly affected by aversion to the noise source, sensitivity to noise, and fear, whereas the noise exposure level and length of residence in the area have a little effect. Regarding the variable “fear,” Janssen et al. (2010) mentioned that fear is a very important factor in the response to aircraft noise, reflecting the important function of fear in the regulation of behavior. This corresponds to the findings of the present study.

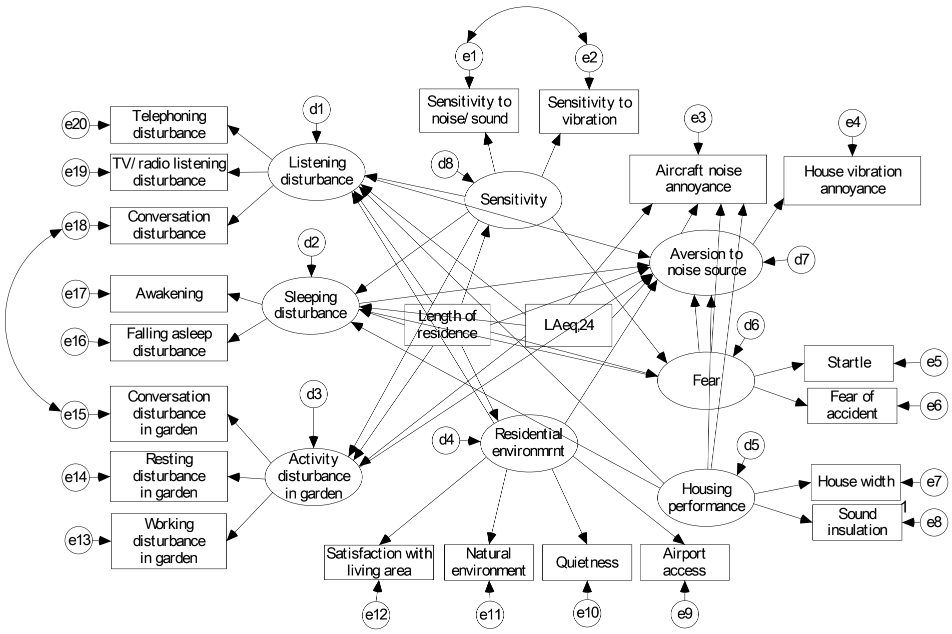



**Figure 6:** Primary structural equation model

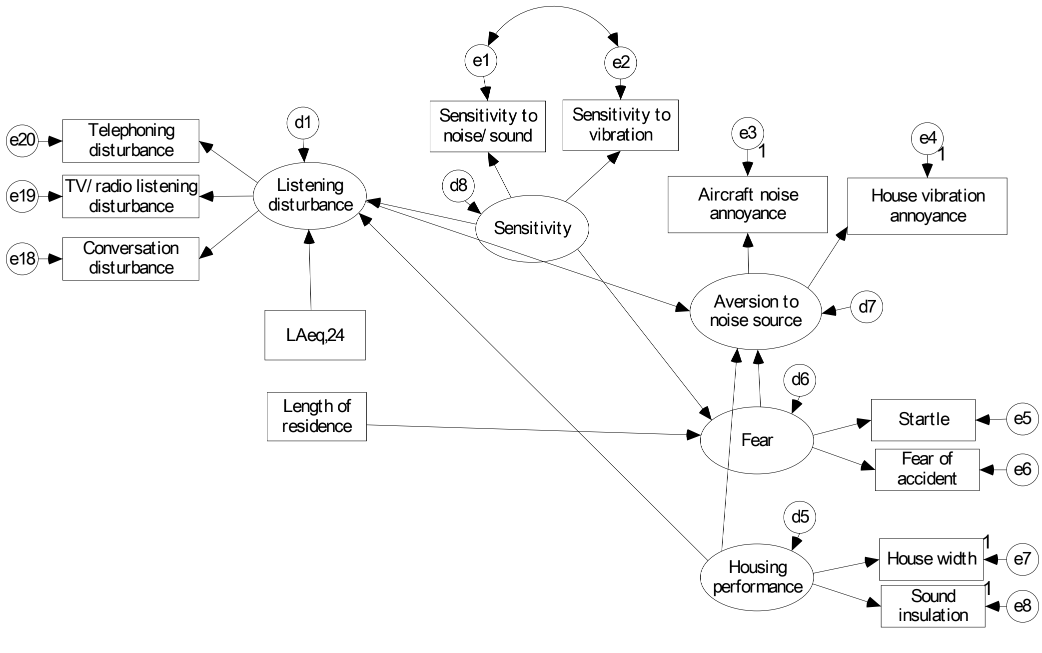



**Figure 7:** Revised model

**Table 5:** Values of fit indices

| GFI | CFI | RMSEA |
|---|---|---|
| 0.945 | 0.967 | 0.058 |

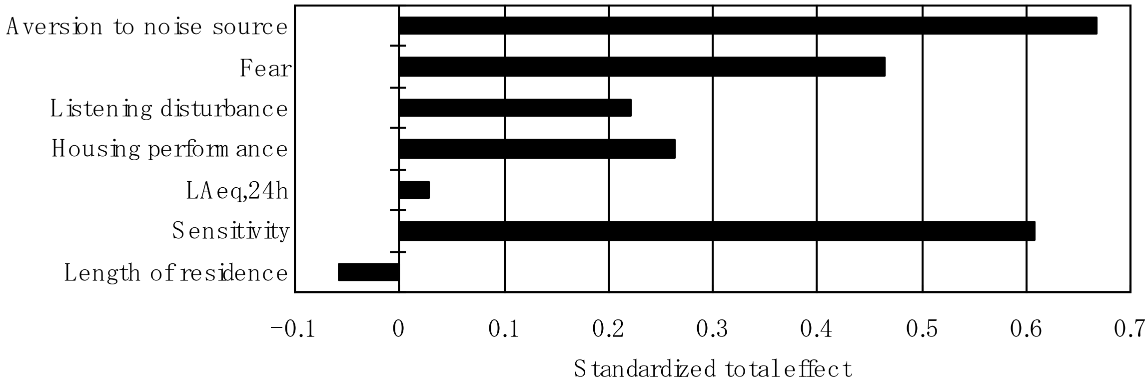



**Figure 8:** Standardized total effects of independent variables on aircraft noise annoyance


## SUMMARY

A social survey was carried out around Okadama airport in Sapporo, Japan, for over two years to investigate the effects of aircraft noise on the local residents. The findings obtained and discussions on dose-response relationships and structural equation modeling are summarized as follows: 1) Helicopters are the dominant noise source around Okadama airport. 2) People seem to respond to the annoyance of both airplane and helicopter noises, even if they are asked about the annoyance due to aircraft noise. 3) The existence of some factors that do not reduce the annoyance in low noise exposure level was suggested. 4) Aircraft noise annoyance is mainly affected by aversion to the noise source, sensitivity to noise, and fear, whereas the noise exposure level and length of residence in the area have only a small effect.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# Effects of residential environmental factors on annoyance and activity disturbances caused by aircraft and road traffic noises in Vietnam

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## INTRODUCTION

In recent years, the annoyance and sleep disturbance caused by transportation noise in European nations have been discussed in conformity with the WHO report 1999 and the Environmental Noise Directive (EC 2002). Babisch et al. 2009 investigated the relation between annoyance and noise exposure ($L_{den}$ and $L_{night}$) at 6 major European airports, and there was no difference between their results and the EU curve for road traffic noise. The annoyance caused by aircraft noise was higher than that predicted by the EU standard curves in the HYENA study, and it was proposed that the current EU prediction curve for aircraft noise annoyance should be modified.

Airplanes fly not only over European countries but also all over other countries throughout the world; hence, the noise policy in Asian countries needs to take the results of European research into consideration. In Japan, the socio-acoustic survey data archive (SASDA) subcommittee which is one of the subcommittees of the Institute of Noise Control Engineering of Japan was established in 2009; one of its objectives is to archive social survey data pertaining to the residential sound environment in Asian countries. Unfortunately, the data on aircraft noise in this archive is insufficient; therefore, it will be necessary to accumulate more data and to expand the target area beyond Japan, to other Asian countries.

The authors have been conducting a social survey of transportation noise in Vietnam since 2005 (Phan et al. 2010; Nguyen et al. 2009, 2010). Vietnam is a developing country, and it has the second largest population in Southeast Asia. It is currently facing many environmental issues such as air, water, and noise pollution, especially in large cities like Hanoi and Ho Chi Minh City. Social surveys of the community response to road traffic noise in Hanoi and Ho Chi Minh City were conducted in 2005 and 2007, respectively (Phan et al. 2010). These surveys indicated the first dose-response relationships between $L_{den}$ and the percentage of highly annoyed in Vietnam. Nguyen et al. (2009, 2010) carried out social surveys on aircraft noise in Hanoi and Ho Chi Minh City in 2009 and 2008, respectively. These studies showed that the dose-response curve for aircraft noise annoyance fits the EU curve in Ho Chi Minh City's data, while the curve in Hanoi's data was slightly higher than the EU curve.

The objective of the present study is to assess whether non-acoustic factors affect noise annoyance and sleep and listening disturbances by re-analyzing the socio-acoustic data in Vietnam.

METHOD

### Data

Social surveys on the community response to road traffic noise were conducted in Hanoi and Ho Chi Minh City using the face-to-face interview method in 2005 and 2007, respectively. Table 1 shows sample sizes and individual characteristics of each survey and the range of noise exposure levels. The number of males and females was almost the same in all surveys. More than half of the respondents were between the ages of 20 and 39.

The road traffic in Vietnam (Hanoi and Ho Chi Minh City) had the following characteristics: motorbikes accounted for around 90 percent of the volume of traffic and many horn sounds were included in this noise. Road traffic noise levels on the most-exposed side of the dwelling were estimated by the 24-hour noise measurement values and the distance reduction equations based on the short-term measurement by using sound level meters (RION NL-21 and NL-22). The range of noise exposure levels was from 62 to 76 dB at $L_{night}$, 65 to 79 dB at $L_{Aeq}$,24h and 70 to 83 dB at $L_{den}$. The combined noise of aircraft and road traffic was measured every one second for 24h on the road shoulder. Aircraft noise exposure was measured every one second for seven successive days using sound level meters (RION NL-21 and NL-22) at the same site. Aircraft and combined noise exposures ranged from 48 to 71 dB and from 70 to 83 dB at $L_{den}$, respectively.

### Annoyance, sleep and listening disturbances

The questions concerning noise annoyance and sleep and listening disturbances were included in the third part of the questionnaire. The questionnaire was divided into four parts. The first part included house data (ownership, size, structure, etc.). The second part pertained to residential environmental issues (satisfaction with the residential areas, comfort in a given season, greenery, view, quietness, convenience, etc.). The third part included noise related questions. The final part included general

**Table 1:** Summary of individual characteristics and noise exposure level

| Description | *N* (%) in Hanoi | | | *N* (%) in Ho Chi Minh | | | Total |
|---|---|---|---|---|---|---|---|
| | Road | Combined | Aircraft | Road | Combined | Aircraft | |
| Gender | | | | | | | |
| Male | 709(49) | 278(51) | 369(46) | 705(50) | 296(46) | 397(48) | 2754(48) |
| Female | 728(51) | 271(49) | 430(54) | 717(50) | 347(54) | 438(52) | 2931(52) |
| Age | | | | | | | |
| 20-39 | 771(53) | 261(47) | 384(47) | 762(53) | 398(62) | 448(54) | 3024(53) |
| 40-59 | 515(35) | 244(44) | 333(41) | 515(36) | 193(30) | 292(35) | 2092(36) |
| ≥60 | 181(12) | 55(10) | 95(12) | 149(10) | 52(8) | 90(11) | 622(11) |
| Range of noise exposure levels | | | | | | | |
| $L_{night}$(22:00-6:00) | 62-76 | 61-73 | 40-51 | 67-76 | 65-76 | 45-62 | 40-73 |
| $L_{Aeq}$,24h | 65-77 | 66-78 | 44-57 | 70-79 | 69-77 | 49-66 | 44-79 |
| $L_{den}$ | 70-83 | 70-82 | 48-61 | 75-83 | 73-83 | 53-71 | 48-83 |

socio-demographic data (age, gender, sensitivity, attitude toward transportation, occupation, and family size).

Noise annoyance was measured on the ICBEN standardized 5-point verbal scale and 11-point numerical scale (Fields et al. 2001; Yano & Ma 2004). Sleep and listening disturbances were also measured according to the recommendation of the ICBEN standardized 5-point verbal scale.

### Statistical analysis

A multiple logistic regression analysis was performed to calculate adjusted odds ratios for the percentage of individuals highly annoyed or experiencing high sleep and listening disturbances, as well as for residential environmental factors in relation to relevant independent variables. These independent variables were categorized between the top 2 categories ("extremely" and "very") and the other three categories. In this paper, residential environmental variables capture the satisfaction with a residential area, its comfort level in the rainy season, the greenery in the residential area, and the quietness of the residential area. SPSS version 11.0 was used for the analysis.

## RESULTS

### Relationship between verbal and numerical scales for noise annoyance

A logistic regression analysis was conducted to investigate the relationship between the five-point verbal scale and the 11-point numerical scale. Figure 1 shows the relationships between noise annoyance and road traffic noise, combined noise and aircraft noise. The black lines reflect the result of the five-point verbal scale, for which the cut-off points are the top category (extremely), top 2 categories (extremely and very), top 3 categories (extremely, very and moderately), and top 4 categories (extremely, very, moderately and slightly), sequentially, from the lower line. The blue lines reflect the results of the 11-point numerical scale, for which the cut-off points are the top category, down to the top 10 categories, sequentially, from the lower line. The top category of the five-point verbal scale in road traffic noise was almost the same as the top 2 categories of the 11-point numerical scale. More specifically, the top category of the five-point verbal scale for the combined and aircraft noises was located between the top and top 2 categories of the 11-point numerical scale. The

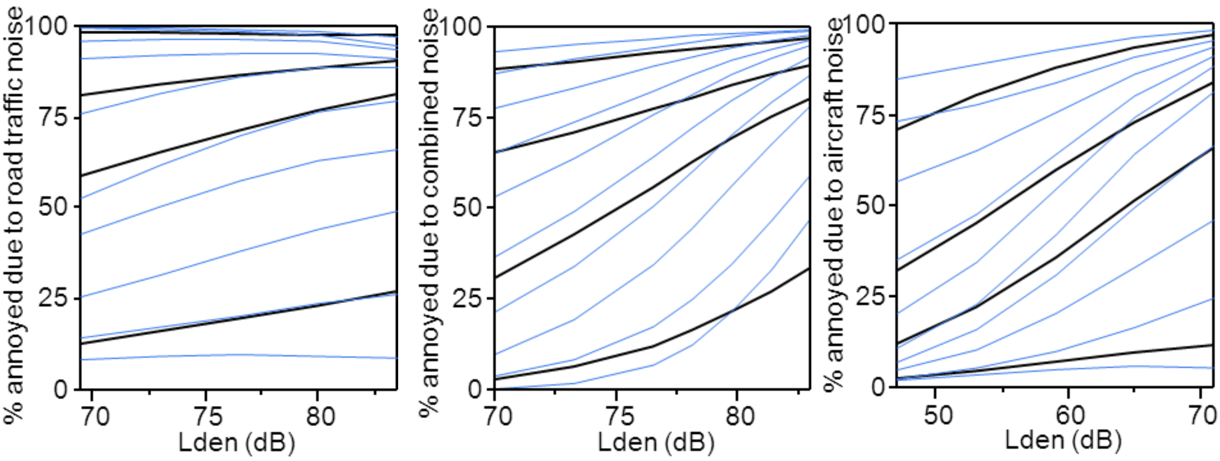


**Figure 1:** Relationships between noise annoyance for different scales and road traffic noise (left), combined noise (middle) and aircraft noise (right): black line; 5-point verbal scale and blue line; 11-point numerical scale

top 2 categories of the five-point verbal scales for all noise sources were almost the same as the top 5 categories of the 11-point numerical scales; that is, these were located between the top 4 and top 5 categories of the 11-point numerical scale. Sato et al. (2004) investigated the relationship between the five-point verbal scale and the 11-point numerical scale using data from the railway noise social survey in Japan. The authors showed that the rate of the % annoyed, for the top category on the five-point verbal scales, was between those of the top two and top three numbers on the numerical scale. Further, they showed that the rate of % annoyed for the top 2 categories on the five-point verbal scale was almost the same as those for the top five numbers of the numerical scale. These results for Vietnam were almost the same as Sato's results.

## Annoyance

Table 2 shows the adjusted odds ratios of person-related variables for a high level of each noise annoyance. The self-reported noise sensitivity influenced noise annoy ance significantly, and the odds ratios for the sensitive group, who responded with "very" or "extremely," were 3.828, 2.532 and 3.168 in the various surveys. This result is the same as that obtained by many past researchers (e.g. Fields 1993; Miedema & Vos 1999; van Kamp et al. 2004; Kishikawa et al. 2009; Jakovljevic et al. 2009). The attitude toward bikes only significantly influenced the road traffic noise annoyance. The safety image of bikes significantly influenced the annoyance caused by road traffic, as well as that caused by combined road traffic and aircraft. The frequency of aircraft use, the attitude toward aircraft and the safety image of aircraft did not influence the annoyance caused by aircraft.

**Table 2:** Odds ratio of person-related variables[1] for a high level of noise annoyance[2].

| Person-related variables | Odds ratio (95 % Confidence Interval) | | |
|---|---|---|---|
| | Road traffic noise | Combined noise | Aircraft noise |
| Self-reported noise sensitivity | 3.828(3.406-4.302)*** | 2.532(2.151-2.981)*** | 3.168(2.707-3.707)*** |
| Frequency of car use | 1.063(0.964-1.172) | 1.057(0.898-1.244) | - |
| Frequency of bike use | 0.966(0.869-1.074) | 0.781(0.669-0.911)** | - |
| Frequency of aircraft use | - | 0.939(0.790-1.117) | 0.928(0.805-1.068) |
| Attitude toward car | 0.981(0.886-1.086) | 1.14(0.929-1.399) | - |
| Attitude toward bike | 1.244(1.126-1.374)*** | 1.039(0.871-1.239) | - |
| Attitude toward aircraft | - | 0.897(0.747-1.078) | 1.131(0.969-1.320) |
| Safety image of car | 0.893(0.753-1.060) | 1.024(0.797-1.315) | - |
| Safety image of bike | 1.253(1.068-1.470)** | 1.621(1.272-2.066)*** | - |
| Safety image of aircraft | - | 0.716(0.578-0.887)** | 0.901(0.746-1.087) |
| Staying time in house | 1.01(0.992-1.028) | 1.003(0.974-1.033) | 0.986(0.961-1.010) |
| Constant | 0.009*** | 0.024*** | 0.021*** |

1 Independent variables included in model: age, gender and area (Hanoi and Ho Chi Minh)
2 Dependent variable: High level of noise annoyance was created by merging "very" and "extremely" annoyed categories
* *p*<0.05, ** *p*<0.01, *** *p*<0.001

Table 3 shows odds ratios of residential environmental variables for noise annoyance. The odds ratios of the satisfaction with the residential area, with respect to road traffic and aircraft noise, were 1.924 and 2.678, respectively. Thus, it was confirmed that people who were not satisfied with the residential areas indicated a high noise annoyance. Furthermore, with respect to road traffic noise, the odds ratios of the comfort level during the rainy season and the quietness of the residential area for noise annoyance were significantly. In contrast, no significant relationship was observed between the greenery in the residential area and the annoyance caused by road traffic or aircraft noise. Li et al. (2010) indicated that greenery perception exerts considerable influence on road traffic noise annoyance ratings, at home. As such, in our next step, it will be necessary to examine whether the same result is obtained in our case.

**Table 3:** Odds ratio of residential environmental variables[1] for noise annoyance[2]

| Residential environment | Odds ratio (95 % Confidence Interval) | | |
|---|---|---|---|
| | Road traffic noise | Combined noise | Aircraft noise |
| Satisfaction with residential area | 1.924(1.038-3.567)* | 1.265(0.624-2.566) | 2.678(1.271-5.641)*** |
| Comfort in rainy season | 2.039(1.508-2.758)*** | 1(0.635-1.573) | 1.215(0.835-1.767) |
| Greenery in residential area | 1.115(0.872-1.427) | 1.169(0.787-1.737) | 1.177(0.806-1.72) |
| Quietness of residential area | 3.947(3.096-5.031)*** | 2.736(1.84-4.068)*** | 1.379(0.923-2.059) |
| Lden | 1.056(1.005-1.109)* | 1.172(1.108-1.24)*** | 1.179(1.136-1.223)*** |
| Constant | 0.000*** | 0.000*** | 0.000*** |

1 Independent variables included in model: age, gender, area (Hanoi and Ho Chi Minh), self-reported noise sensitivity, frequency of use of transport, attitude to noise sources, safety image of noise sources, and actual time spent in the house and area

2 Dependent variable: High level of noise annoyance was created by merging “very” and “extremely” annoyed categories

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

## Sleep disturbance

The result of our analysis of whether sleep disturbance is influenced by the residential environmental variables is presented in Table 4. The odds ratios associated with people who were not satisfied with residential areas increased with sleep disturbance, when dealing with road traffic and combined noises. In contrast, it had no significant influence with aircraft noise. The relationship between the greenery in the residential area and sleep quality was significant ($p<0.05$). It was found that people who respond severely with respect to comfort in the rainy season and the quietness of the residential area tended to have slightly high odds ratio, but this was not significant in any of the three noise environments. Öhrström et al. (2006) showed that the sleep disturbance of people who had a quiet side in their house was lower than those who did not, when dealing with road traffic noise. The benefit of access to a quiet side for sleep ranged from 8 % to 18 %. Further study and analysis are needed to gain a better understanding of sleep disturbance.

## Listening disturbance

It was investigated whether the TV/radio listening disturbance was influenced by the four residential environmental variables. This was done using multiple logistic regression (Table 5). The odds ratio associated with the satisfaction with the residential area was significant with respect to road traffic and combined noises, but it was not of significant influence for aircraft noise. The other three residential environmental vari-

**Table 4:** Odds ratio of residential environmental variables[1] for sleep quality[2]

| Residential environment | Odds ratio (95 % Confidence Interval) | | |
|---|---|---|---|
| | Road traffic noise | Combined noise | Aircraft noise |
| Satisfaction with residential area | 3.696(2.463-5.545)*** | 4.964(2.557-9.636)*** | 1.937(0.939-3.997) |
| Comfort in rainy season | 0.814(0.597-1.11) | 1.094(0.651-1.836) | 1.366(0.883-2.113) |
| Greenery in residential area | 1.425(1.056-1.923)* | 0.928(0.566-1.522) | 1.303(0.827-2.055) |
| Quietness of residential area | 1.061(0.756-1.488) | 1.580(0.948-2.63) | 1.570(0.995-2.475) |
| $L_{night}$ | 0.997(0.942-1.055) | 1.079(1.013-1.149)* | 0.989(0.946-1.035) |
| Constant | 0.002** | 0.000*** | 0.019** |

1 Independent variables included in model: age, gender, area (Hanoi and Ho Chi Minh), self-reported noise sensitivity, frequency of use of transport, attitude to noise sources, safety image of noise sources, and actual time spent in the house and area

2 Dependent variable: High level of sleep distubance was created by merging "very" and "extremely" annoyed categories

* *p*<0.05, ** *p*<0.01, *** *p*<0.001

ables also influenced TV/radio listening disturbance significantly. This result for the road traffic noise survey was the same as Öhrström's (Öhrström et al. 2006) result. The odds ratio for the greenery in the residential area was significantly high (*p*<0.05), but the comfort level in the rainy season and the quietness of the residential area were not of significant influence. In regard to aircraft noise, this disturbance was not influenced by these four residential environmental variables.

**Table 5:** Odds ratio of residential environmental variables[1] for TV/radio listening disturbance[2]

| Residential environment | Odds ratio (95% Confidence Interval) | | |
|---|---|---|---|
| | Road traffic noise | Combined noise | Aircraft noise |
| Satisfaction with residential area | 1.731(1.205-2.488)** | 2.005(1.007-3.989)* | 1.188(0.607-2.328) |
| Comfort in rainy season | 1.403(1.123-1.752)** | 1.101(0.656-1.848) | 1.352(0.918-1.991) |
| Greenery in residential area | 1.609(1.286-2.013)*** | 1.793(1.103-2.915)* | 1.133(0.76-1.688) |
| Quietness of residential area | 1.345(1.041-1.739)* | 1.202(0.733-1.972) | 0.933(0.617-1.41) |
| $L_{Aeq}$,24h | 1.031(0.983-1.081) | 1.264(1.195-1.336)*** | 1.146(1.103-1.191)*** |
| Constant | 0.001*** | 0.000*** | 0.000*** |

1 Independent variables included in model: age, gender, area (Hanoi and Ho Chi Minh), self-reported noise sensitivity, frequency of use of transport, attitude to noise sources, safety image of noise sources, and actual time spent in the house and area

2 Dependent variable: High level of TV/radio listening disturbance was created by merging "very" and "extremely" annoyed categories

* *p*<0.05, ** *p*<0.01, *** *p*<0.001

## CONCLUSIONS

In this paper, we presented the results of an examination of whether person-related and residential environmental variables would influence the relationship between transportation noise and noise annoyance, as well as sleep and listening disturbances in Hanoi and Ho Chi Minh City, Vietnam. With respect to the result of the investigation of the relationship between the five-point verbal scale and the 11-point numerical scale, the top 2 categories of the five-point verbal scales were almost the same as the top 5 categories of the 11-point scale; it was located between the top 4 and top 5 categories of the 11-point numerical scale. The relationship between noise annoyance and person-related variables, evaluated using multiple logistic regression, indicated the presence of a significant effect from self-reported noise sensitivity, to road traffic noise, aircraft noise and the combination of the two. The attitude toward and the safety image of bikes also influenced road traffic noise annoyance. This may change according to future traffic situations in Vietnam. With respect to road traffic noise, it was shown that these four residential environmental variables influence noise annoyance or activity disturbances. On the other hand, although it was shown that the satisfaction with a residential area influences noise annoyance with respect to aircraft noise, the influence of other variables was not observed.

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# Comparing models to predict the combined noise annoyance in Ho Chi Minh City and Hanoi

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## INTRODUCTION

Many residential communities especially in the urban areas of crowded and dense population city where the interference of many activities associated with the flow of variety of vehicles occurred are exposed by not only a single but also multiple sources. It means an environment composed of simultaneous occurrence of different noises, namely, combined noise source. The complex mechanism of the combined noise annoyance raises the need for efficient and simple prediction tools to evaluate its impact. Several previous studies regarding various models providing methods for predicting annoyance response to combined noise source have been published. Ollerhead's model named "Response and summation" was guided by the boundary condition that if one of the component sources masks all other sources the total annoyance must equal the response to that single source (Ollerhead 1978). A summation and inhibition model developed by Powell (1979) provides for the summation of the subjective magnitudes of annoyance due to the separate noise sources and for the inhibition of the subjective magnitudes of each source by the presence of the other noise sources.

This paper was inspired by the work of Taylor (1982), in which the powers of five models were compared for predicting annoyance reaction to mixed sources using data in the vicinity of Toronto International Airport. The result showed the energy difference model to be the most powerful predictor of mean total annoyance and the simple energy summation model to be the weakest. This finding confirmed the importance of absolute level differences between sources. Taylor also emphasized the need of further studies adding to the evidence provided by his analysis.

The socio-acoustic surveys conducted in the vicinity of the airports of the two largest cities in Vietnam where busy highways and roads concentrate. The residents are exposed to not only aircraft but also road traffic noise. Therefore, the impact of aircraft noise in Vietnam should be assessed in association with the impact of road traffic noise, in other words, as a combined noise of aircraft and road traffic. In the previous paper on these surveys, the dose-response curves for aircraft noise annoyance obtained in areas exposed to single noise showed to be different from that of areas exposed to combined noise source (Nguyen et al. 2009, 2010). In the survey in Hanoi, when the noise exposure level is lower than 55 dB, the two curves are entirely parallel together with % highly annoyed difference of about 6 %. Above 55 dB aircraft noise annoyance in the combined noise survey steeply increases and the two curves are crossed each other at about 60 dB. This is opposite to the trend obtained in Ho Chi Minh Survey 2008. It is noteworthy that all the sites exposed to aircraft noise around main airports in Vietnam were also exposed to heavy road traffic noise. This shows the difference of characteristics of noise around the airports in Vietnam in comparison with Toronto Airport that was investigated in Taylor's paper. Hence, the social survey on combined noise of aircraft and road traffic noise in Vietnam can provide material to conduct more analysis to extent the discussion on the valid rating model for combined noise source. The final conclusion was still left open in Taylor's study.

In this paper, in addition to five models reviewed in the study of Taylor, two other models will also be taken into consideration. They are "Annoyance equivalents model" proposed by Miedema (2004) and "Dominant source model" developed by Rice and Izumi (Rice & Izumi 1984). Their research suggested the use of a dominant source model by which the total noise annoyance could be predicted by using the source specific annoyance of the most annoying of the noise sources.

The present study is expected to open for further analysis by using the data collected around the two largest airports in Vietnam before definitive conclusions can be drawn. The purpose of the present study is to find out the most powerful model in rating the annoyance caused by combined noise source determined by the traffic situation in Vietnam.

## DATA COLLECTION

### Site selection

The two cities chosen for the surveys are the busiest major metropolitan areas in Vietnam. In these cities, the effects of transportation noise on the health of the urban population continue to grow. The increase in transportation noise is due to rapidly increasing urbanization and industrialization. Tan Son Nhat Airport in Ho Chi Minh City and Noi Bai Airport in Hanoi are the two largest international airports in Vietnam. However, the handling capacity of Noi Bai Airport is only less than half of Tan Son Nhat Airport. Tan Son Nhat Airport is located inside a crowded residential area of Ho Chi Minh City with busy commercial streets. Noi Bai Airport is located among rural and scatted-populated areas far from downtown Hanoi and but right in the hub of many national arterial roads and industrial zones. Since the situations of the vicinity around the two airports were quite different, the validity of models will be examined separately for the data of the two airports.

Ten residential areas were selected around Tan Son Nhat Airport including eight sites under the landing and takeoff paths of aircraft and two other sites laying to the north and south of the runway. Nine sites were selected around Noi Bai airport including seven sites under the landing and takeoff paths of aircraft and two sites to the south of the runway. The site selection was intended to reflect the aircraft noise exposure covering locations at various distances from and directions relative to the airport. All houses selected in the combined noise areas at each site were facing the road with various traffic volumes in the vicinity of the airports.

## Social surveys

Social surveys on community response to aircraft noise and combined noise from aircraft and road traffic were conducted around Tan Son Nhat Airport in Ho Chi Minh City from August to September 2008 and around Noi Bai Airport in Hanoi from August to September 2009. Community responses were obtained through an interview questionnaire presented as a social survey of the living environment. The responses to combined noise source were collected from residents of the houses facing the roads that were considered to be exposed to both aircraft and road traffic noise.

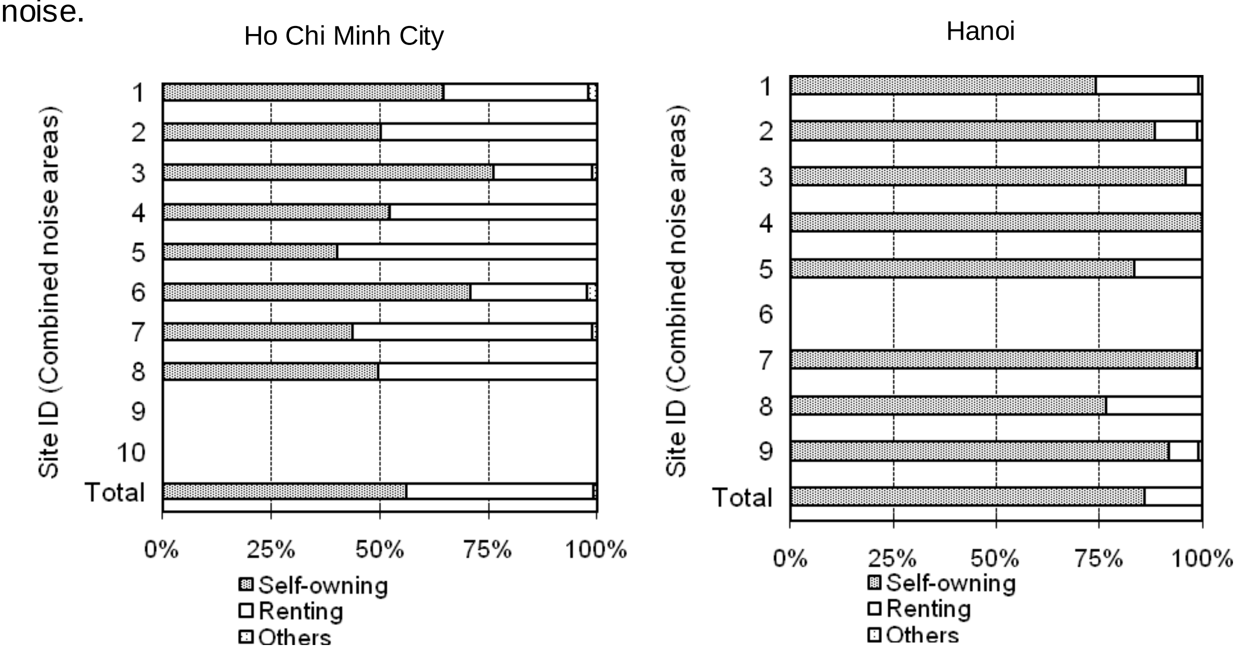


**Figure 1:** Component of the house‘s ownership types

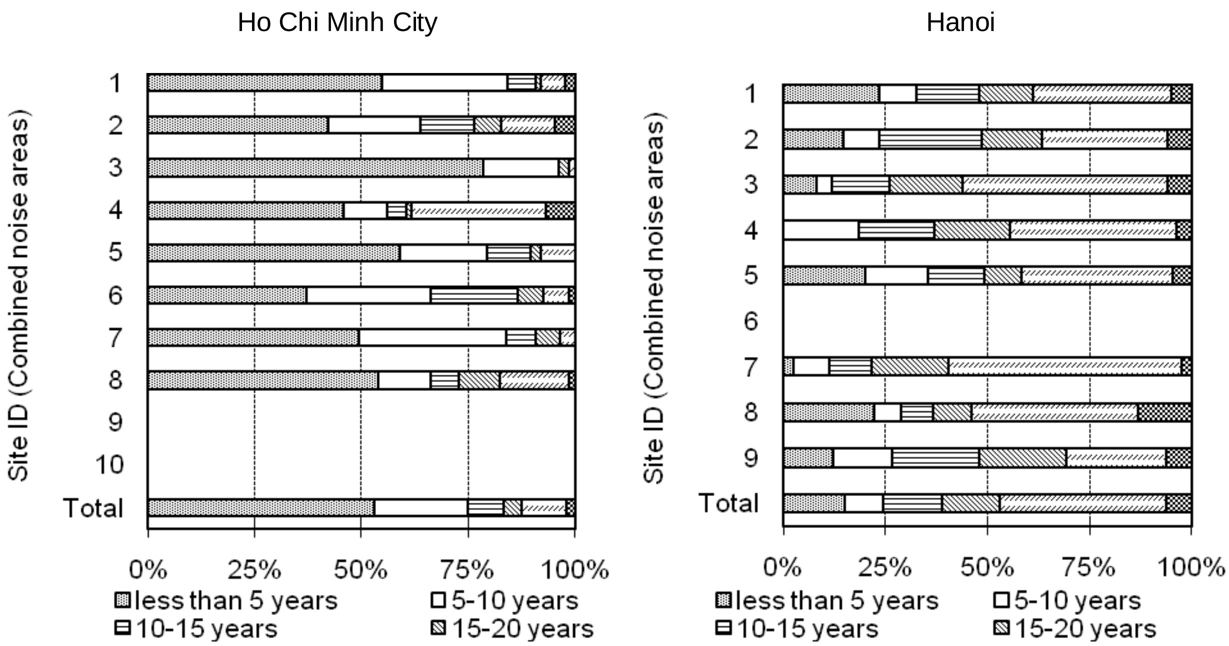


**Figure 2:** Length of residence

In the questionnaire, two scales — 5-point verbal and 11-point numeric — constructed according to the ICBEN (International Commission on Biological Effects of Noise) method were used to evaluate the respondents' noise annoyance (Yano & Ma 2004). The respondents were asked to evaluate their annoyance simultaneously to all three types of noise sources. They are aircraft, road traffic and combined noise of both. In this paper, the data from 11-point numeric question were used.

Ho Chi Minh City and Hanoi have different features with particular social and climate conditions. Figure 1 compares the respondents' house types obtained from the surveys in Ho Chi Minh City and Hanoi. The result reveals that the rate of respondents living in their own houses in Hanoi is higher than in Ho Chi Minh City. The rate of respondents that lived over 20 years in their houses in Hanoi is clearly higher than those in Ho Chi Minh City (Figure 2). Both cities are the major economic centers of Vietnam and attracting the huge number of migrants from the neighborhood areas. This result is consistent to the findings of Douglass et al. 2002 that presented migration rates of inter-provincial migrants are 23 percent and 8 percent for Ho Chi Minh City and Hanoi, respectively. Ho Chi Minh City has tropical climate with high and stable temperature, while Hanoi lies in the north with monsoonal climate with hot summer with high rainfall and cold winter, rare of rain. This might cause a different habituation of population in two cities.

### Noise measurements

Noise measurements were performed in Ho Chi Minh City from September 22 to 29, 2008, and in Hanoi from September 10 to 17, 2009, by applying the same method in both cities. The combined noise of aircraft and road traffic was measured every 1 s for 24 h on the road shoulder. Aircraft noise exposure was measured every 1 s for seven successive days by using sound level meters (RION NL-21 and NL-22) at the same site but for the areas rather separate from the road which is supposed to be exposed to mainly aircraft noise. Road traffic noise metrics were calculated by energy subtraction of aircraft from combined noise metrics. The aircraft and combined noise exposures ranged from 53 to 71 dB and 73 to 83 dB $L_{den}$ (from 49.4 to 65.8 dB and 69.4 to 76.9 $L_{Aeq, 24h}$) in Ho Chi Minh City and from 48 to 61 dB and 70 to 82 dB $L_{den}$ (from 44.2 to 56.8 dB and 68.8 to 77.9 $L_{Aeq, 24h}$) in Hanoi, respectively.

## RESULTS AND DISCUSSION

In this section, the data are used to examine the validity of combined noise models. The annoyance at each site was calculated by the unweighted mean of the individual annoyance score. The 24-hour average sound level $L_{Aeq, 24h}$ and average annoyance scores for aircraft, road traffic, and combined noise obtained from the surveys in Ho Chi Minh City and Hanoi are summarized in Tables 1 and 2, respectively. In Ho Chi Minh City, aircraft noise exposures ranged from 49.4 to 65.8 dB while road traffic noise exposure ranged from 69.3 to 76.9 dB at all sites. The average annoyance scores ranged from 0.5 to 7.7 for aircraft noise and from 3.8 to 8.9 for road traffic noise. In Hanoi, aircraft noise exposures ranged from 44.2 to 56.8 dB while road traffic noise exposure ranged from 65.7 to 77.9 dB at all sites. The average annoyance scores ranged from 1.6 to 7.9 for aircraft noise and from 4.7 to 8.4 for road traffic noise. It is clear to realize that in both Ho Chi Minh City and Hanoi, road traffic noise was shown to be not only physically but also psychologically dominant at all sites.

**Table 1:** Noise exposure and annoyance data in Ho Chi Minh City

| Site ID | Noise level $L_{Aeq}$ (dB) | | | Mean annoyance score | | | N |
|---|---|---|---|---|---|---|---|
| | Aircraft | Road | Combined | Aircraft | Road | Total | |
| 1 | 54.2 | 71.1 | 71.2 | 3.2 | 4.3 | 4.4 | 59 |
| 2 | 49.4 | 76.9 | 76.9 | 0.5 | 8.9 | 8.9 | 57 |
| 3 | 49.4 | 69.3 | 69.4 | 7.7 | 3.8 | 5.9 | 54 |
| 4 | 52.0 | 70.7 | 70.7 | 2.7 | 4.1 | 3.5 | 88 |
| 5 | 65.8 | 75.1 | 75.6 | 7.0 | 7.8 | 8.2 | 87 |
| 6 | 59.0 | 74.3 | 74.5 | 5.4 | 6.6 | 5.7 | 84 |
| 7 | 59.8 | 73.8 | 74.0 | 6.3 | 4.2 | 4.9 | 85 |
| 8 | 56.8 | 71.8 | 71.9 | 5.9 | 7.1 | 7.0 | 85 |

N: Number of respondents

**Table 2:** Noise exposure and annoyance data in Hanoi

| Site ID | Noise level $L_{Aeq}$ (dB) | | | Mean annoyance score | | | N |
|---|---|---|---|---|---|---|---|
| | Aircraft | Road | Combined | Aircraft | Road | Total | |
| 1 | 49.8 | 66.5 | 66.6 | 1.6 | 4.7 | 4.0 | 94 |
| 2 | 51.0 | 72.9 | 73.0 | 3.3 | 8.4 | 7.7 | 67 |
| 3 | 56.8 | 72.8 | 73.0 | 7.9 | 8.4 | 8.6 | 51 |
| 4 | 52.5 | 68.9 | 69.0 | 7.7 | 7.9 | 8.0 | 26 |
| 5 | 44.2 | 71.1 | 71.1 | 3.3 | 7.8 | 6.8 | 67 |
| 7 | 52.7 | 71.0 | 71.1 | 2.7 | 7.5 | 7.3 | 73 |
| 8 | 56.1 | 77.9 | 77.9 | 4.5 | 8.0 | 7.8 | 59 |
| 9 | 47.2 | 65.7 | 65.8 | 3.1 | 6.4 | 5.0 | 92 |

N: Number of respondents

The situation of surveyed sites in Taylor's study was quite different (Taylor 1982). The noise levels obtained in Taylor's study were from 55.6 to 71.1 dB for aircraft noise and from 52.2 to 69.9 dB for road traffic noise. The average annoyance scores were from 2.17 to 6.46 for aircraft noise and from 0.13 to 4.33 for road traffic noise. The aircraft and road traffic noise were quite comparable physically and aircraft noise was psychologically dominant. Such data indicates the different combination of aircraft and road traffic noise between two studies. Moreover, though 11 point numeric scale (0-10) was used in both surveys, the end point label was "extremely annoyed" in our study and "unbearably disturbed" in Taylor's.

In this part, linear regression analysis is applied to estimate the effects of aircraft and road traffic noise on annoyance. The individual annoyance scores and noise data are used to formulate the regression equations, in which the aircraft $L_{Aeq(24h)}$ ($L_{AC}$), the road traffic $L_{Aeq(24h)}$ ($L_{RT}$ ) and the cross production of $L_{AC}$ and $L_{RT}$ ($L_{AC}L_{RT}$) are used as independent variables for exploring the compositions of annoyance including total, aircraft and road traffic annoyance. The results are shown in Table 3. The aircraft $L_{Aeq(24h)}$ had significant effect at level $p<0.05$ and $p<0.01$ on total annoyance in Ho Chi Minh City and Hanoi, respectively. Total annoyance in Hanoi was significantly influenced at effective level $p<0.01$ by road traffic $L_{Aeq(24h)}$. The influence of aircraft and road traffic noise were opposite between the two cities that is negative for Ho Chi Minh City and positive for Hanoi. In contrast, interferences of slopes of two sources have positive effect on total annoyance in Ho Chi Minh City but negative for that in Hanoi. These findings emphasize different compositions of total annoyance between the two cities. It is noteworthy that while aircraft annoyance has the opposite mechanism, road traffic annoyance shows to be the same composition between the two cities. Moreover, no factor other than road traffic $L_{Aeq(24h)}$ significantly affects road traffic annoyance. In other word, this indicates an independence of road traffic annoyance from affecters. These findings imply the dominant role of road traffic noise in a mixed noise environment of all surveyed sites around Tan Son Nhat and Noi Bai Airport which are exposed to very heavy road traffic.

**Table 3:** Total, aircraft and road traffic annoyance as function of source $L_{Aeq}$

| Equation | | | | | | | | | | | $R^2$ | Std error |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ho Chi Minh | | | | | | | | | | | | |
| $A_T$ = | 80.948 | - | 2.220 | $L_{AC}$* | - | 0.983 | $L_{RT}$ | + | 0.030 | $L_{AC}L_{RT}$* | 0.200 | 2.465 |
| $A_{AC}$= | 301.464 | - | 5.106 | $L_{AC}$** | - | 4.231 | $L_{RT}$** | + | 0.073 | $L_{AC}L_{RT}$** | 0.351 | 2.294 |
| $A_{RT}$= | -128.191 | + | 1.709 | $L_{AC}$ | + | 1.81 | $L_{RT}$* | - | 0.023 | $L_{AC}$ $L_{RT}$ | 0.262 | 2.423 |
| Hanoi | | | | | | | | | | | | |
| $A_T$ = | -160.129 | + | 2.851 | $L_{AC}$** | + | 2.296 | $L_{RT}$** | - | 0.039 | $L_{AC}$ $L_{RT}$** | 0.280 | 2.191 |
| $A_{AC}$= | -49.723 | + | 0.960 | $L_{AC}$ | + | 0.583 | $L_{RT}$ | - | 0.010 | $L_{AC}L_{RT}$ | 0.134 | 2.729 |
| $A_{RT}$= | -72.247 | + | 1.156 | $L_{AC}$ | + | 1.152 | $L_{RT}$* | - | 0.017 | $L_{AC}L_{RT}$ | 0.152 | 2.402 |

** $p<0.01$, * $p<0.05$
$L_{AC}$ = Aircraft, $L_{Aeq(24h)}$ (dB), $L_{RT}$ = Road traffic, $L_{Aeq(24h)}$ (dB),
$A_T$ = Individual total annoyance score, $A_{AC}$ = Individual aircraft annoyance score, $A_{RT}$ = Individual road traffic annoyance score

In the next step, the multiple regression analysis was applied to compare how well seven models predict the observed data obtained in Ho Chi Minh City and Hanoi (Table 4). The regression equations are calculated by fitting a model to the data for which the sum of the squared differences between the line and the actual data points is minimized. The coefficient of determination $R^2$ indicates the percent that the model accounts for variability in the total noise annoyance. For example, in Table 4, $R^2$ is 0.474 in the energy summation model, indicating that the model accounts for 47.4 % of the variability in the overall annoyance. The standard error (Std error) of the estimate for regression measures the amount of variability in the points around the regression line.

The regression equations of seven combined noise models calculated for the data obtained in Ho Chi Minh City and Hanoi were shown in Table 4. The coefficient of determination $R^2$ of the regression equations for Ho Chi Minh City data indicated that the energy difference model estimated the total annoyance ($R^2$ = 0.49) better than energy summation, independent effects, response summation, summation and inhibition, and annoyance equivalents models ($R^2$ = 0.25–0.48). This result is consistent to Taylor's study at Toronto International Airport. The regression equations of seven models for Hanoi data show that the energy difference model ($R^2$ = 0.58) estimated the total annoyance slightly better than energy summation ($R^2$ = 0.53), independent effects ($R^2$ = 0.53) and annoyance equivalents models ($R^2$ = 0.54), but less effective than response summation ($R^2$ = 0.62) and summation and inhibition ($R^2$ = 0.62). This is partly different from Taylor's which can be explained by the differences in ranges of aircraft and road traffic noise exposures between two studies. These results confirm again the importance of absolute level differences between sources in their effects on a total annoyance.

**Table 4:** Regression equation for combined noise source models

| Model | | | | | | $R^2$ | Std error |
|---|---|---|---|---|---|---|---|
| **Ho Chi Minh City** | | | | | | | |
| Energy summation | $A_T$ = | -29.97 | + | 0.49 | $L_T$ | 0.47 | 1.47 |
| Independent effects | $A_T$ = | -30.41 | + | 0.53 | $L_{RT}$ - 0.03 $L_{AC}$ | 0.47 | 1.61 |
| Energy difference | $A_T$ = | -30.48 | + | 0.49 | $L_T$ +0.05 $L_{DIFF}$ | 0.49 | 1.58 |
| Response summation | $A_T$ = | -28.53 | + | 0.47 | ($L_T$ +10.25*$10^{(Lac - Lt/10)}$ ) | 0.48 | 1.60 |
| Summation + inhibition | $A_T$ = | -13.26 | + | 0.25 | $L_{T(CORR)}$ (D=12) | 0.25 | 1.75 |
| Annoyance equivalents | $A_T$ = | 40.75 | + | 0.62 | L | 0.44 | 1.51 |
| Dominant source | $A_T$ = | -0.52 | + | 1.00 | $A_D$ | 0.82 | 0.85 |
| **Hanoi** | | | | | | | |
| Energy summation | $A_T$ = | -14.30 | + | 0.30 | $L_T$ | 0.53 | 1.17 |
| Independent effects | $A_T$ = | -14.65 | + | 0.23 | $L_{RT}$ + 0.098 $L_{AC}$ | 0.57 | 1.23 |
| Energy difference | $A_T$ = | -14.86 | + | 0.33 | $L_T$ - 0.095 $L_{DIFF}$ | 0.58 | 1.23 |
| Response summation | $A_T$ = | -18.88 | + | 0.35 | ($L_T$ + 171.096*$10^{(Lac - Lt/10)}$ | 0.62 | 1.17 |
| Summation + inhibition | $A_T$ = | -16.18 | + | 0.32 | $L_{T(CORR)}$ (D=7) | 0.62 | 1.06 |
| Annoyance equivalents | $A_T$ = | -14.77 | + | 0.31 | L | 0.54 | 1.17 |
| Dominant source | $A_T$ = | -1.99 | + | 1.20 | $A_D$ | 0.90 | 0.53 |

However, the coefficient of determination $R^2$ is 0.82 and 0.90 for the dominant source models for the surveys in Ho Chi Minh City and Hanoi, respectively. They are also the highest value among all other models. The dominant source model implies that the overall annoyance is always equal to the highest single source annoyance. Though Miedema criticized the dominant source model in that it does not describe the empirical data correctly since the total annoyance increases if the annoyance level of non-dominant source approaches that of the dominant source (Miedema 2004), $R^2$ is highest for the dominant source models of both surveys in Ho Chi Minh City and Hanoi, suggesting that it is the most useful model in rating the total noise annoyance. This result can be explained by the case of the vicinity of the airports in Vietnam, where the difference in noise level between two sources is rather large (as shown in Table 1 and 2). This finding also confirms an early mention about a dominant role of road traffic noise in mixed noise environment around airports in Vietnam.

## CONCLUSIONS

Since the dominant source model is to explain the total annoyance with the subjectively dominant source-specific annoyance and the other models are to explain with the objective noise levels, the superiority of the dominant source model could not be directly compared with the others. The much higher correlation coefficients of dominant source model in rating the total noise annoyance was confirmed in Vietnam where road traffic noise was more dominant than aircraft noise. This is convenient in such situation that dose-response curves are established separately for different noise sources.

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# Noise and health in the greater Rotterdam area

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## INTRODUCTION

As from 1994 the provincial and local authorities in the Rotterdam Metropolitan Area already realized that joint monitoring of the regional environmental situation was essential to an effective environmental policy. Since then, fifteen so called MSR reports on the Rotterdam region have been published. In the early years, the environmental quality appeared to improve visibly. More recently, however, on balance no further progress has been made. The explanation for this is that in the nineties, the 'easy' environmental problems could be solved through stringent source policies; the initiative at that time lay with the major polluters, mainly industries. As a consequence of this the difficult problems remained, which were mostly caused by diffuse sources. For example, noise nuisance is caused, among other things, by road and air traffic, and industry, while shipping traffic and road traffic are important sources of air pollution. Since there are usually a number of authorities responsible for tackling these diffuse sources, effective cooperation between these authorities is a prerequisite. Thus within MSR the most important authorities in the Rotterdam region environmental field are represented. By jointly sketching an integral picture of the environmental situation in the region, in MSR, these authorities can also jointly take those measures which are necessary in order to tackle the diffuse sources.

The goal of MSR is twofold. In the first place MSR aims at tracking the progress of environmental policy in the region and indicating new developments relating to environmental quality, free from value judgments. In this way MSR contributes to the policy cycles of the authorities who work together in MSR. Administrators and their staff thus obtain information which enables them to place, evaluate and, if necessary, adjust their policy in a broader context. Based on this information, they can also formulate new policy or speed up its implementation. Where no verifiable policy objectives are available, indicators in any case perform a warning function so that timely adjustments are still possible. In the second place, MSR informs residents and the business sector about the state of the environment in the Rotterdam region and its recent developments. In this way MSR fulfils the obligation that authorities have, in the framework of the Aarhus treaty, to supply environmental information to their residents. Furthermore, MSR responds to the societal need for transparent government.

The last MSR report was published mid-2010. During more than 15 years the monitoring program and report were elaborated. At first, only environmental themes as noise, air- and soil pollution were reported and developments on environmental permitting and enforcement of these permits. The very last report comprises indicators on energy, sustainable mobility, waste, water, air quality, noise, external safety, green and nature, space and also health. Environmental themes are cross border issues with other policy fields like economy, green, spatial- and urban planning, mobility et cetera. This is in particular true for noise. The number of noise indicators has increased during the past years. This paper mainly goes into the surveys that were done in 2008, the Environmental Perception Survey (Van Vliet et al. 2008) van conducted in 2007[1] and the Rotterdam Noise Map as meant in article 7 of the END (European Noise Directive 2002) and some underlying reports as the MSR report on Noise, Health and Money (Van Wijk et al. 2008).

## NOISE IN THE ROTTERDAM METROPOLITAN AREA

From earlier surveys, the so called Deltaplan Noise (Maat et al. 2000) and the CBA 2nd Maasvlakte (Eijgenraam et al. 2001) which was conducted by DCMR, commissioned by the CBS[2], it was found that the Rotterdam Metropolitan Region encounters a lot of noise from industrial premises, roads, railways and aviation. This was established by the consolidated noise map that was produced based on the four separated noise maps for the END, see Figure 1.

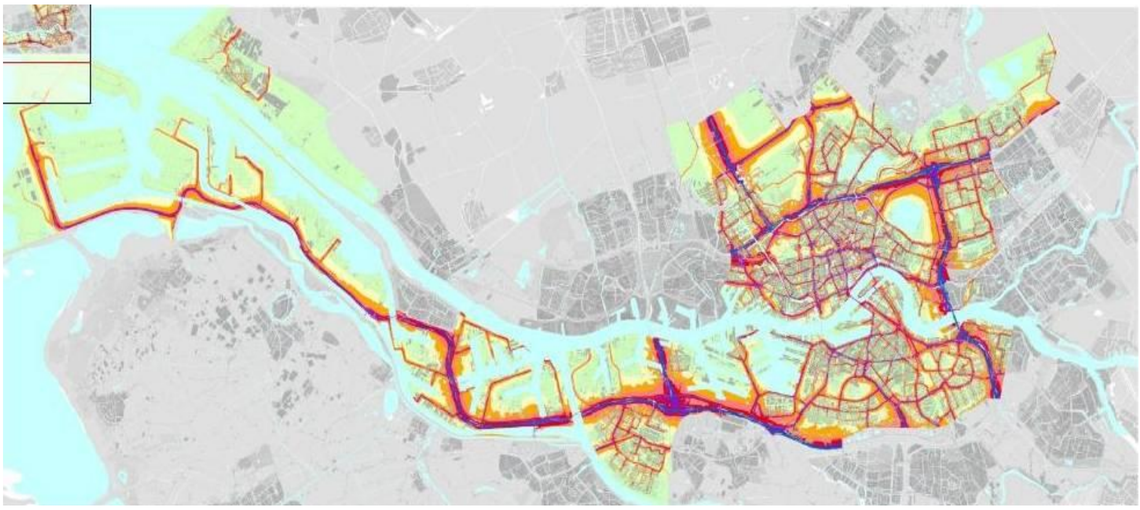

**Figure 1:** Consolidated Noise Map Rotterdam 2008

In the Rotterdam Metropolitan Area, which harbors the largest port of Europe and the third in the world, many noise sources are present. The region comprises more than 22,000 enterprises, 350 km's of motorways, 250 trunk roads, 250 local roads and 100 km's of railways. The region is very crowded, around 1.2 million citizens are living in this region and 400,000 laborers are working in the harbor, the factories, offices et cetera. At this time, the city of Rotterdam has 560,000 inhabitants and is the second largest city of The Netherlands. The Rotterdam Metropolitan Region contributes approximately 13 % of the Dutch Gross Domestic Product. A small business airport is situated north of Rotterdam, which causes a lot of complaints.

## NOISE, HEALTH AND MONEY

Within the MSR program, it is more or less a custom to produce a special theme report, besides the overall report on all components. In 2008 a theme report on noise has been drafted and published. Besides indicators on money a lot of noise indicators were reported like number and percentage of inhabitants exposed per noise class and per type of noise, annoyed and highly annoyed people, people that encounter sleep disturbance, severe sleep disturbance and even the so called DALY's. The graphs and tables within the theme report are based on the findings of the Rotterdam Noise Map. Beside the map on traffic noise, industrial noise, railway noise

[1] Reported in 2008
[2] CBS is the Dutch Bureau for Statistics

and aviation noise, the consolidated noise map was produced and a map with potential quiet areas as well. A few of these findings are depicted below.

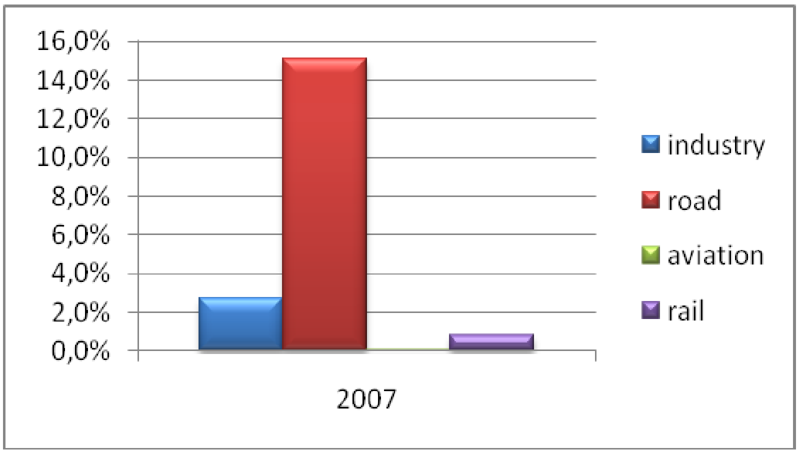


**Figure 2:** Percentage of annoyed people

The Figure shows that road traffic noise is by far the most troublesome noise. This is plausible that road traffic noise affects the most people in Rotterdam. The number of exposed people by road traffic noise amounts almost 18,000. The Figure of the exposed people stays behind in this paper but can be found at the website of MSR, www.hetmilieuinderegiorotterdam.nl.

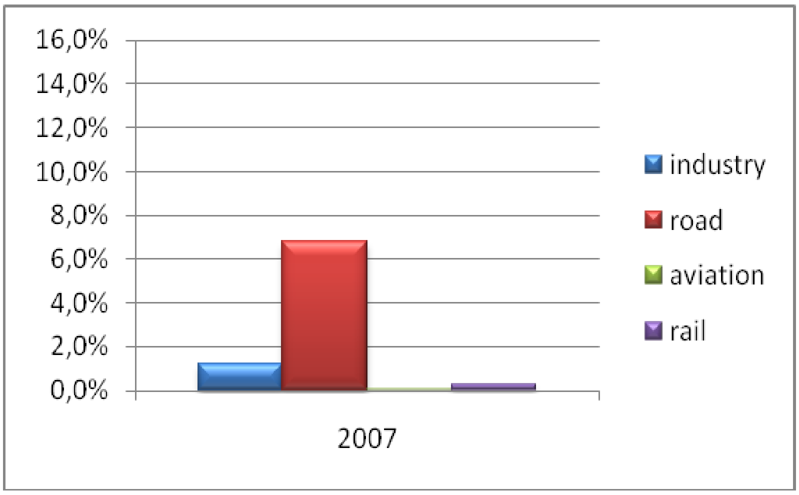


**Figure 3:** Percentage of highly annoyed people

The same applies for highly annoyed people. About 7 % of the 'Rotterdammers' are subject to high annoyance. It looks that industrial noise and railway noise hardly do not play a role. Although, expressed in real numbers, there are almost 20,000 citizens exposed to noise that is annoying and around 8,000 citizens to noise that result in high annoyance. The number of people that is exposed to aviation noise (from the Rotterdam Airport) is rather low (198 versus 64 for annoyance and high annoyance).

The report on Health and Money memorizes also the number of DALY's due to road traffic noise and industrial noise. This is given in Table 1.

It is also stated in the report that noise, especially long lasting noise caused irreversible health effects in men like high blood pressure, cardiovascular diseases like heart attacks and strokes which could be fatal. It is estimated that the number of fatalities, due to long lasting noise, in the Rotterdam Metropolitan Region amounts to 35-40 per annum.

**Table 1:** Disabled adjusted life years

| Rotterdam and the DALY's | |
|---|---|
| **High annoyance** | |
| **Road traffic** | 715 |
| **Rail traffic** | 39 |
| **Aviation** | 16 |
| **Industry** | 364 |
| **Severe Sleep Disturbance** | |
| **Road traffic** | 363 |
| **Rail traffic** | 27 |

ENVIRONMENTAL PERCEPTION SURVEY

Every two years this survey is conducted by the province of South Holland for the whole province which includes also the Rotterdam Metropolitan Region. In this paper, the results for noise are subject to a further analysis. The survey is done by telephone and partly by the Internet. As from 2005 the so called ICBEN scale has been used. In the previous years, a 5-point scale was used. In the comparisons made in the survey report a conversion has been made to transpose the 5-point scale into a 11-point scale. Some of the findings of the EPS are depicted below. The survey conducted in 2007 is reported in 2008.

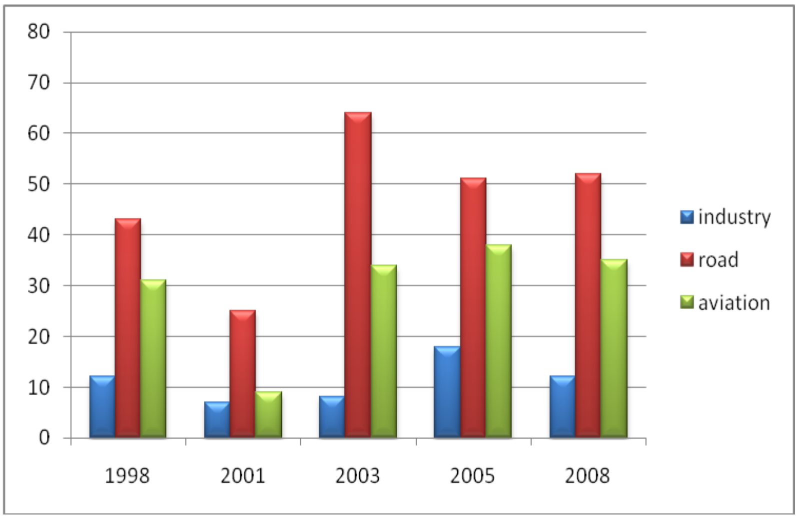


**Figure 4:** Percentage of annoyed people (ESP)

In the perception of the 'Rotterdammers' road traffic noise is by far the most annoying followed by aviation noise. Industrial noise is ranked at the third place. Railway noise is not included in the EPS unfortunately. It is striking to see that the perception of the citizens is varying from year to year. Only in the case of aviation there is a reason for the drop in 2001. In that year, the class 2 airplanes have been phased out. The variation found in road and industrial noise cannot be explained so far.

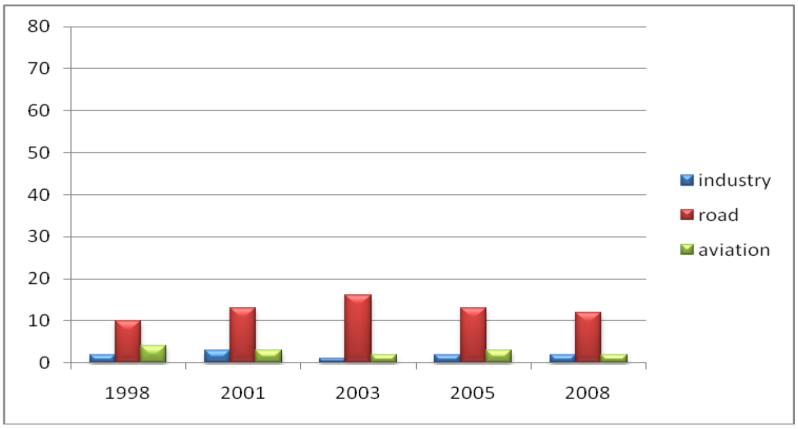


**Figure 5:** Percentage highly annoyed people (EPS)

## NOISE COMPLAINTS

The registration room for incidents and complaints of DCMR EPA has registered noise complaints since 1973 when DCMR EPA was founded. Noise and stench complaints are the most complaints submitted by the citizens. A lot of the complaints are about aviation. The last year complaints from bars, cafés and discos are increasing. Despite all kinds of measures like phasing out chapter 2 planes, sanitation of industrial and road traffic noise, the trend is going up. Only aviation noise goes slightly down the last three years.

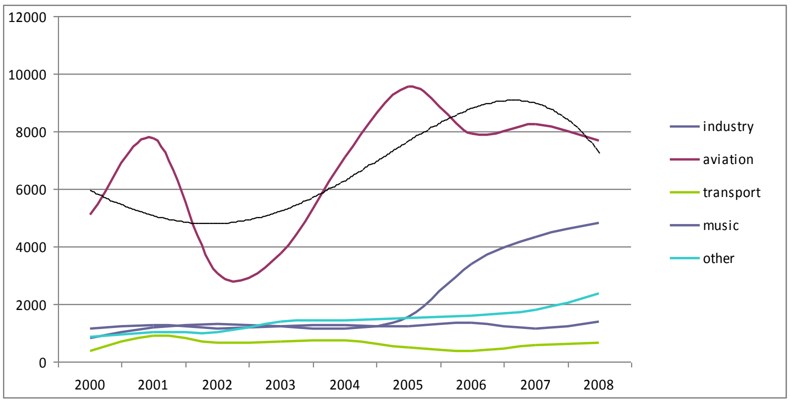


**Figure 6:** Noise complaints (2000-2008)

It is widely known that there is no direct relation between the number of complaints and the perceived noise in terms of annoyance, sleep disturbance, etc. Non-acoustic factors are also playing an important role at noise levels lower than 65-70 dB $L_{day}$. Noise complaints on aviation noise are strongly influenced by a few complainers. Around 10 % of the complainers have submitted 75 % of the complaints!

## COMPARISONS

As recommend by the WHO noise levels above 55 dB $L_{den}$ should be avoided because as from this point high annoyance occurs in human. A map was made in order to show the extent of houses and sensitive objects[3] in the Rotterdam municipality that are exposed to noise higher than 55 dB $L_{DEN}$. A part of this map is depicted in Figure 7.

[3] like schools, hospitals, nursing homes, et cetera

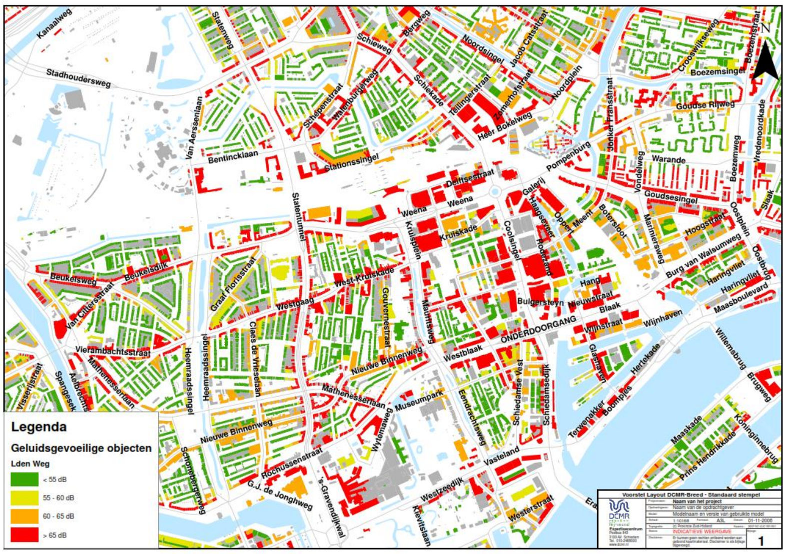


**Figure 7:** Houses exposed > 55 dB $L_{DEN}$

Due to the high expenses of measures and the impracticality of them, it was decided to use a higher threshold of 63 dB. For the night, a similar map was made. The threshold value according to the WHO recommendations amounts 40 dB $L_{night}$. As in many cities the $L_{night}$ seems to be a forgotten parameter. The map with the houses that are exposed to 40 dB $L_{night}$ and higher is depicted in Figure 8.

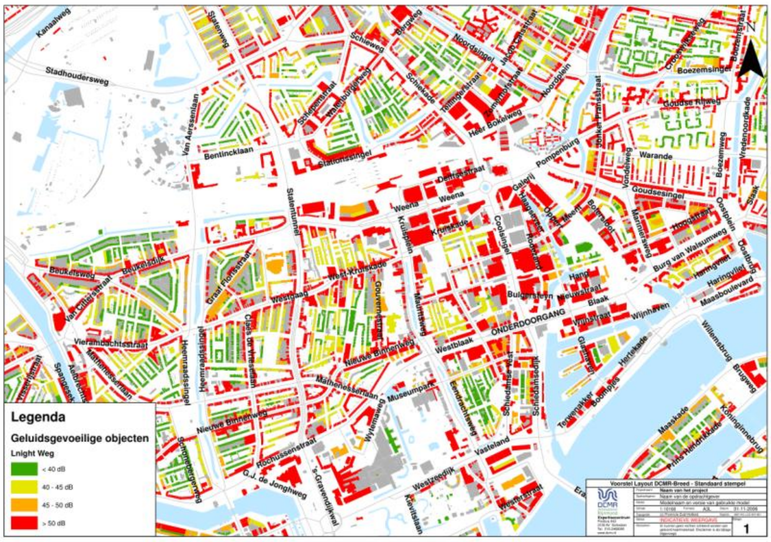


**Figure 8:** Houses exposed to >40 dB $L_{night}$

As 40 dB is the interim value recommend by the WHO and 35 dB the preferred limit value on the long term, it can be noticed that a lot of houses and sensitive objects cannot comply with these limit values and that measures will be needed in a drastically way. It can be doubted if the preferred noise limits are feasible because effects of local measures are limited. (Wolfert 2009).

A comparison was made for the estimated and the reported annoyance and high annoyance for the year 2007/2008.

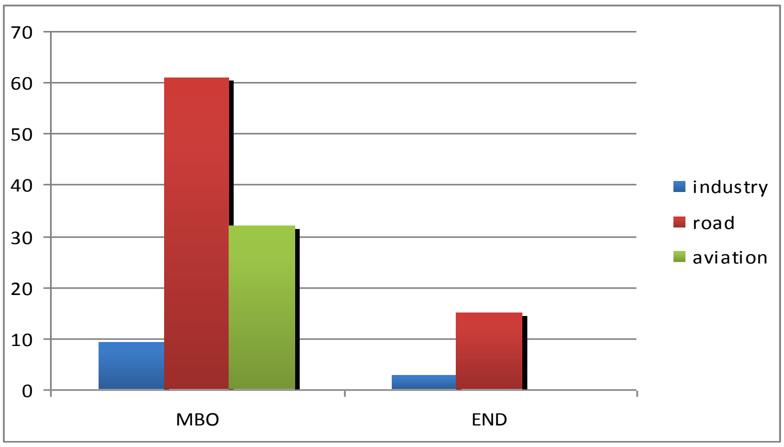


**Figure 1:** Annoyed people EPS versus END

The figure shows that there is a remarkable difference between the annoyance reported in the EPS and the annoyance estimated on the noise map according to the END. In the EPS the scores are 4 times higher than estimated with the noise maps results using the Miedema dose-response curves. Aviation noise hardly does not have estimated annoyance (0.03) because it assumed that $L_{DEN}$ is not a proper metric for aviation noise to express annoyance or high annoyance for this type of small airports. People refer annoyance to the 'over flights' peak levels and number of over flights and not on a yearly based averaged.

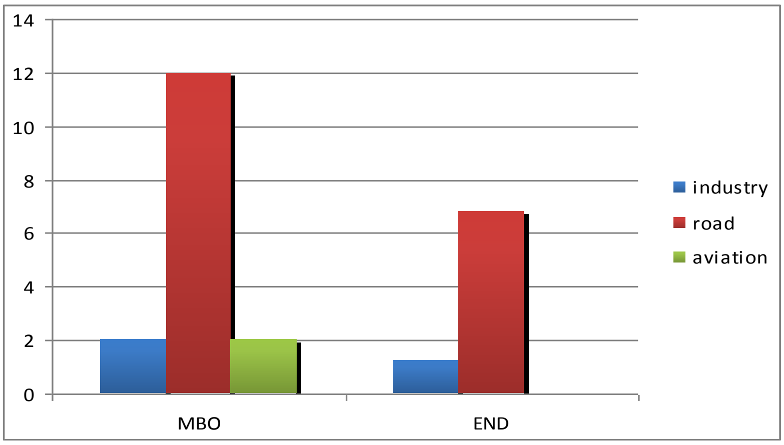


**Figure 10:** Highly annoyed people EPS versus END

For highly annoyed the difference is less than for annoyance, notwithstanding there is about a factor 2 between EPS and END findings. Knowing that field surveys certainly do not exactly match with estimations based on noise maps numerous reasons can be reported, among them:

1. Inaccuracy of the noise calculations due to the modeling, the validity of the method at given distances in the Rotterdam Metropolitan Region (>700 m), assumptions, missing data et cetera, which could give an underestimation.
2. Local circumstances in Rotterdam could have an important influence. Compared to other cities, Rotterdam has a high percentage people with a low income and a high percentage of members from another ethnic entity (± 50 %). Especially the group originated from non-western countries are assumed less sensitive to noise because it was found that they hardly

complain about noise (DCMR EPA, 1997). Due to this, one should expect that a reverse view should occur.

3. Noise levels are assessed as from 50 dB while it is known that annoyance occurs as from 42 dB $L_{DEN}$ and sleep disturbance from 35 dB. A huge number of people exposed to noise levels between 42 dB and 50 dB are excluded because the noise map only shows the noise levels above 50 dB $L_{DEN}$ and $L_{NIGHT}$. This gives an underestimation as well.
4. The samples made (number of people interviewed) in the EPS amount (472) which is about 0.08 % which could be too low. Within the 95% Confidence Interval an error range of ± 4.5 % is estimated in the report.
5. The questions in the EPS questionnaire let some room for interpretation and could be improved. Example: it is not clear if mopeds, scooters are included in the questions and they are included in the calculations! From survey done before it is known that mopeds and scooters in cities are perceived as very annoying (Sandberg 2002).
6. Non-acoustic factors possibly could have influenced the reported perception in the EPS (Findell & Stallen 2009), especially the people classified as annoyed.
7. Applying the Miedema curves at a smaller -local- scale introduces inaccuracies because dose-response relations for traffic noise and annoyance appear to be scale-specific: relationships established at international levels sometimes deviate from national relationships; in turn these relations can deviate from regional ones. For policies this means that consideration should be given to the limitations and transferability of (inter-) national exposure-response relationships used in local situations (Breugelmans et al. 2007).
8. Although, the Miedema curves might be the best we currently have, it is widely known that there is still some room for improvement. A few things should be improved:
   a. The study used the so called cut-off points (45 dB and 75 dB); from other studies (not noise) it known that this could influence the results. A sensitivity analysis could raise some insight if other cut-off points, e.g. as from 35 dB will deliver other results.
   b. Those curves are partly based on old data (1970-1980); since then lifestyle has drastically changed in the western world. It could be considered to exclude the old data and to add recent data in order to estimate updated curves. In some of the older surveys only the percentage of highly annoyed was estimated and some surveys comprised limited data for high noise levels originated by rail and road traffic which should be an extra reason to skip those data (Giering 2010).
   c. The Miedema curves are also based on data from other continents, like North America and Australia. Culture and habits differ from the 'European culture' if there is a European culture. Cities, especially city centers in Europe differ from cities in North America, these are rather new and have structures, which are more car friendly. It is known that car use in North America is more common than in Europe. E.g. more than 75 % of the Canadians goes every day by car, in the 8 major agglomer-

ations is somewhat lower (± 68 %, 2006). In Australia it is almost the same (Australian Bureau of Statistics). In EU27 car use is lower.

d. The conversion from $L_{DN}$ to $L_{DEN}$ includes a number of assumptions which could influence the findings; is the conversion applicable to highways and smaller roads in cities both, where no continuous flow of traffic appears?
e. The conversion of the 3 or 5 points scale to the 11-points ICBEN scale has introduced some inaccuracies because of the questions that differed in the distinguished surveys and it is assumed that offering people a more detailed scale a more balanced input will obtained.

## CONCLUSIONS

From Figures 4 and 5 can be concluded that human perception on noise is not a stable factor but more like the stock markets. It can vary from year to year. Reasons could be incidents that have been occurred, media attention, spatial developments near district, et cetera.

Outcomes of 'calculated noise effects' differ remarkably from those that were found during field surveys like the EPS. Some divergence could be expected taking into account the scattering of data points and the 95 % confidence level. Significant divergence can be addressed to numerous causes, see above.

For politicians and policy makers those discrepancies are confusing and do not contribute to better understanding of the noise and the noise.

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# Human response to vibration in residential environments: A seven year journey to establish exposure-response relationships

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## INTRODUCTION

The project "Human Response to vibration in residential environments" is the culmination of seven years of research funded by the Department for Environment, Food and Rural Affairs (Defra) UK. The aim of the research was to investigate the relationship between human response in residential areas, primarily in terms of annoyance, and combined effects from exposure to vibration and noise. The project steering group for the project consisted of technical staff appointed by the Department for Environment, Food & Rural Affairs (Defra), and representatives of the British Standards Institution working group for BS6472 (Guide to evaluation of human exposure to vibration in buildings), and the UK Association of Noise Consultants (ANC) vibration working group.

This paper presents an insight into the role of the project steering group, the technical considerations made during the progress of the project, the interface with the three contractors who delivered the scoping stage, the pilot stage and the main study respectively, and a review of the results of the main study delivered by the University of Salford, and what they may mean for future technical and policy development on vibration.

## PROJECT INCEPTION

Following written representations from the ANC in 2002 to Defra, a working group was appointed to explore the possibility of determining a dose-response relationship between vibration and human response in a residential environment. Defra agreed that the project was worthy of funding through the Noise and Nuisance Research Program, and appointed Richard Perkins of Parsons Brinckerhoff Ltd to manage the project, and to lead the steering group.

The first actions for the steering group were to consider the nature of the project, and the various technical requirements required of the appointed contractor. Following a series of technical workshops, during which the mechanics of vibration measurement and social survey techniques were debated at length, the steering group arrived at a final specification of work. The work would involve the development of a methodology to measure the vibration dose, a social survey questionnaire, and a methodology to undertake both in a field trial.

## SCOPING STUDY

The Scoping study was let through a competitive tender to a consortium led by David Trevor-Jones & Associates in 2004. They developed a hypothesis to enable further consideration of the methodology for the study to be undertaken. The location and method of acquiring the vibration data was of particular relevance, and how to deal with extraneous data was debated. The various types of measuring equipment were analysed, and evaluated for their various merits for a study of this kind. The scoping study resolved a number of technical issues, such as whether measurements should be internal or external, and how to develop a robust method for analysing the data.

On the social survey side, questionnaires were trialled to test the various words used to describe vibration – whilst noise questionnaires are well established, little work had been done previously on the human response to vibration, so these had to be developed during the project.

## PILOT STUDY

The Pilot Study was again let through a competitive tender to a consortium of Arup Acoustics, Temple Group, Transport and Research Laboratories & the Institute of Sound and Vibration Research in 2005. The results from the Scoping Study were reviewed and developed, leading in the summer of 2006 to the finalisation of a measurement methodology and social survey questionnaire that was ready to be trialled in the field.

Before the field trials were approved, a number of workshops were held between the contractor and the Defra steering group, with both methodologies given a thorough examination and critique from both the steering group members and a number of external reviewers.

The steering group were generally in agreement on most topics, but some differences of opinion were found in some areas, particularly on whether vibration could be treated independent of its source. It therefore followed that a consensus approval was given to proceed to the field trials.

The field trials were completed in the autumn of 2006, and a final report ((March 2007) Human Response to Vibration in Residential Environments) delivered to Defra in January 2007. Presentations of the results of the Pilot Study were made to the Institute of Acoustics “Rumble in the Jungle” seminar in March 2007. The final report was then published on the Defra website.

The Pilot Study demonstrated that the measurement methodology and social survey protocol developed had been successfully trialled in the field, and an ordinal relationship could be derived from correlation of the subjective responses to the vibration input for a railway source.

## MAIN STUDY

An internal review followed the publication of the pilot study report, and the steering group met a couple of times to discuss the results, and to draft the specification for the main study. The membership of the steering group was boosted with the addition of Henk Miedema and Sabine Janssen of TNO to assist with the social survey side of the project.

The project was let to the University of Salford in January 2008 for a three year study into the human response to vibration in residential environments.

Their work began with a review of the pilot study findings, and the production of a list of other issues that required further consideration by both the contractor and the steering group before the field studies could be commenced. This work took a full year, but included an international peer review of the social survey methodology before submittal to Defra.

The measurement protocol, social survey questionnaire and field protocol were completed and again a consensus approval was given by the Defra steering group to commence the field studies in the summer of 2009. Railway sources were targeted in the first case studies.

Field studies continued until late autumn, at which point the weather and available daylight hours prevented further progress until the spring of 2010. The winter months were spent processing and analysing the data, and preparing a modified set of protocols for other vibration sources such as construction and internal sources.

The summer of 2010 was spent getting the last field studies, whilst at the same time data analysis was underway. A draft final report was delivered to Defra in January 2011, and a final report submitted for Defra's review in April 2011. Publication of the final report is due soon.

A number of Oral presentations and Poster sessions are being presented to the ICBEN 2011 conference related to the project, and I will not steal their thunder, except to say that a dose response relation does appear to exist, and the dataset appears to be robust.

## NEXT STEPS

The submittal of the final report now presents Defra with a significant wealth of technical evidence to show the relationship between vibration and human response to vibration exposure in residential environments on which future policy development can be based. It is further hoped that the evidence can assist with future updates of British Standard BS6472.

## ACKNOWLEDGEMENTS

I would like to take this opportunity to publically acknowledge all of the people involved with the project and the countless hours put into making this project the success that it undoubtedly is. This includes the aforementioned contractors who did all of the hard work, the main steering group of Colin Grimwood, Colin Stanworth, Rupert Thornely-Taylor, and in the early days Stephen Turner of Defra (formerly Bureau Veritas). Thanks also go to the various people who assisted in peer reviews and proof reading of the contractor reports from the ANC vibration working group, and my Parsons Brinckerhoff colleagues on the Defra research support team of Ian Sherlock, Richard Jackett and Rebecca Hutt.

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**The final paper was not available at deadline.**

# Assessment of annoyance caused by different types of construction noises

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ABSTRACT

In the present study, annoyance caused by diverse construction noises was evaluated through surveys and laboratory experiments. A survey with a total of 100 construction workers was carried out to investigate annoyance from construction noises at different construction phases. Then, a number of noises from machinery that were evaluated in the survey as highly annoying were recorded from construction sites in Korea. Recorded construction noises were classified into four groups: stationary, fluctuating, intermittent, and impulsive, according to the temporal, psychoacoustical and spectral characteristics of the noises. A laboratory auditory experiment was then performed in order to quantify the total annoyance caused by individual construction noise and multiple construction noises. From the experiment, synthesis curves were derived for the relationship between noise levels and the percentage of highly-annoyed (%HA) and the percentage of annoyed (%A) for the combined noise sources.

**The final paper was not available at deadline.**

# Community response to low frequency noise from power plants by gas turbine engine generator. Correlations among European studies and Peruvian related cases. Results of four years researching work with more than 300 stakeholders showing health problems

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ABSTRACT

This paper presents the results of more than four years to research and investigation of community response to low frequency complaints, all of these from engines which use natural gas as combustible. Since 2005 the natural gas has been used to produce electricity in Peru, and the power plants were built at the same place that the old ones in the middle of residential neighborhoods or even on open spaces nearby suburbs. The environmental acoustic impact was high and the previous statement doesn't account the social and health issues of the people, mainly because the study was conducted by non-acousticians, and all prediction measurements were made using "A" frequency weighting (not spectral). Because of the people who live in the vicinity of the one power plant, they presented several complaints at different Government Authorities asking for an environmental impact statement would cover all aspects: acoustic, health issues, psychological annoying, etc. The authors of this paper have been initiated the researching work in order to achieve the explanation for the great number of stakeholders. Firstable, were conducting measurements using "C" and "G" frequency weighting and 1/3 octave band, and the results were compare and correlated to European's with accuracy among them and the percentage of Peruvian annoyed people. Health problems were found with environmental noise under 50 dBA and very high acoustical energy in the low frequency range. The major concern is lying onto night hours because the noise is more noticeable affecting children and older people sleeping.

**The final paper was not available at deadline.**

## Quantitative evaluation of annoyance from military shooting noise

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ABSTRACT

Noise has always been an important environmental problem for man. Thus, a number of studies have been done on noise annoyance such as traffic (road, railway, aircraft) or industrial noise. In comparison to these noise sources, however, shooting noise is relatively less studied. In addition, there are various types of firearms that determination of the rating sound level for shooting noise is complicated. From the early studies, annoyance on shooting noise should be separated by caliber of firearms and A-weighted sound exposure level correlates well with annoyance. In this study, laboratory test was carried out with shooting noise recorded at military firearm ranges. A dose-response relationship is established, and it is compared to that of traffic and wind turbine noises. This study also investigates effects of consecutive single shots on annoyance.

# Estimation of vibration exposure in residential environments

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## ABSTRACT

The University of Salford has derived an exposure-response relationship for vibration in residential environments. Vibration measurements have been used for assessing the human exposure alongside a social study questionnaire based on face-to-face interviews for quantifying the human response. This paper deals with the exposure side of the study. In order to cover the wide range of exposures affecting the living environment, various types of vibration activity have been measured, namely: railway, construction and domestic activity. Different and novel measurement approaches have been adopted for assessing the internal vibration exposure in almost 1,000 dwellings. This paper describes the methodologies used for deriving the estimate of the exposure for each vibration source considered and also provides some results. [Work funded by the Department for Environment, Food and Rural Affairs (Defra) UK]

## FORMULATION OF THE PROBLEM

The exposure is defined as the ‘quantity’ of vibration to which a hypothetical resident is exposed inside their property from vibration sources that are outside of their control, assuming that they remain indoors during the period of exposure. Different types of vibration may affect a living environment and can be grouped in the following categories (BSI 2008): transient, continuous and random.

For providing the wide range of exposure affecting the residential environment, in the framework of the Defra project “Human Response to Vibration in Residential Environment” (Waddington et al. 2011), different vibration sources have been considered, specifically: railway activity, construction activity and internal or domestic activity.

In order to develop an exposure-response relationship a high number of case studies are needed. A total of 1,431 case studies were made, including 931 for railway, 350 for construction and 150 for internal vibration sources. In this scenario the living environment has been defined as the dense group of dwellings within a radius of 100 meters from the vibration source for increasing both the range of the exposure and the potential number of respondents. It can be helpful to break down the vibration propagation through the residential environment in 4 areas identified as: source, path, receiver and human body.

The vibration perceived by the human body at the ‘point of entry’ (contact surface between the human body and the vibrating receiver) is due to the complex interaction of the vibration created at the source with the other areas identified above. Each of these regions can amplify or reduce the frequency content of the vibration source. Therefore, these factors need to be taken into account for a complete understanding and estimation of the exposure.

Vibration sources can affect the residential environment in a more or less permanent way, like railway traffic, or in a transitory way such as vibration from a construction site. This last characteristic has to be considered in the evaluation of the exposure. As well as potentially affecting the annoyance from vibration it also has major implications for both the measurement and calculation of exposure and in the coordination with the social team in charge of the measurement of response.

In order to estimate the exposure from the sources considered in the study different methodologies have been developed. The latter are described in the following section.

## METHODOLOGIES

For evaluating the human exposure, the vibration needs to be considered in the frequency range encompassing the range of human sensitivity. The magnitude and duration of the vibration need to be taken into account and possibly also its temporal characteristic such as repeatability.

The vibration exposure is generally quantified with a weighted energy average descriptor such as rms velocity for continuous or random vibration, and for impulsive sources of vibration, peak particle velocity or acceleration is used. However, BS 6472-1 adopts an dose-based exposure metric that can be used for assessing exposure for any type of vibration: the Vibration Dose Value ($VDV_{b/d,day/night}$).

$$VDV_{b/d,day/night} = \left[ \int_0^T a_w(t) \cdot dt \right]^{0.25}$$

where $a_w(t)$ is the frequency-weighted acceleration measured (in $ms^{-2}$), using $W_b$ or $W_d$ as appropriate; and T is the period (in *s*) during which the vibration occurs.

In the framework of the project “Human Response to Vibration in Residential Environments”, the human exposure has been evaluated with measurements, so different source specific methodologies have been created for the measurement (Peris et al. 2011) and the estimation (Sica et al. 2011) of the exposure with different metrics.

The environmental vibrations were measured in the field using a Guralp CMG-5TD (Guralp 2007) strong motion tri axial accelerometer with a low pass filter at 100 Hz. The instrument is a force feedback transducer with low noise floor associated (~10$\mu\ ms^{-2}$ across the frequency range of interest) and an in-built 24-bit digitizer. The ease of use of the system, and the ability to synchronize multiple units via GPS allowing phase-locked measurements, made these accelerometers ideal for this project.

The estimation of the exposure relies on two measurement types: long term measurement and short term measurement. Long term measurement with a minimum duration of 24 hours is used for characterizing the activity of the vibration source. Single short term measurement, usually with an average duration of 30 minutes, has been used for evaluating the impact of the vibration within the respondent property as close as possible to the point of entry. External short term measurements with accelerometers arranged in an array configuration were also used for assessing the vibration attenuation through the residential environment.

The source specific methodologies are presented in the following sub sections.

## Exposure from railway vibration

Railway activity is considered a random vibration source that acts external to the residential environment. Furthermore, railway vibration affects the residential environment in a semi-permanent way. The semi-permanent nature of the source made it possible for the social survey team to arrive on site ahead the vibration team, conducting as many interviews as possible (Condie et al. 2011). Before visiting the site, the vibration team booked an appointment with the respondents who had agreed to have an internal measurement. According to BS 6472-1 the internal measurement should last at least 24 hours in order to determine the full vibration exposure. However, this could not practically be achieved, due to the huge extent of the survey (931 case studies); therefore an alternative measurement procedure was implemented (Woodcock et al. 2009) meeting “half way” the needs of both project and standard. The measurement procedure can be summarized in the following points:

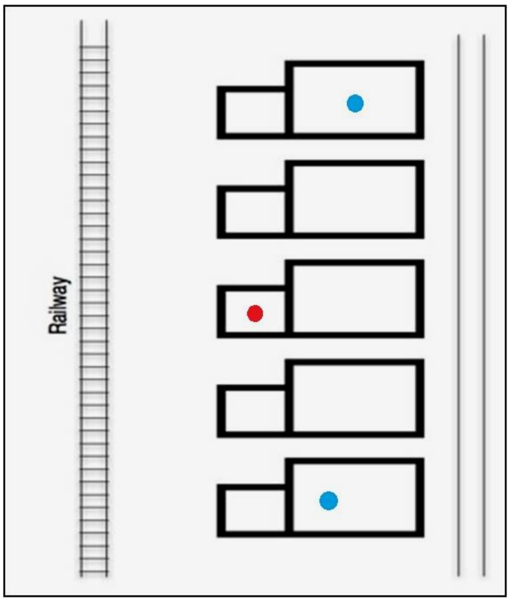


**Figure 2**: Overview railway site

1. 24 hour long term monitoring measurement (control position) in proximity of the residential properties (red dot Figure 2).
2. Synchronized short term monitoring measurement within the property as close to the point of entry as possible (blue dot Figure 2).
3. Calculation of control-to-internal velocity ratio.
4. Calculation of the long term exposure from the results of 1 and 3.

During the long term monitoring period, the vibration team collected as many internal measurements as possible. For each of these cases the measured velocity ratio, obtained by averaging over a few train passages (generally more than six), was used as a filter for scaling the activity recorded at the control position inside the respondent’s property. In this way, a 24 hour estimate of internal vibration activity was obtained from which various exposures could be evaluated.

The success of the methodology can be judged by the fact that an internal measurement was made for 56 % of the properties at which interviews were obtained. In this way a good sampling of the internal vibration activity in the measurement sites was achieved. The estimation of the exposure for the case studies where internal measurements weren't allowed was based on the internal exposure obtained from measurement inside a nearby property of a similar type and at a similar distance from the railway. This kind of estimation was thought to be more reliable than those obtained from external measurements outside the property.

## Exposure from construction activity

Construction activity can generate different types of vibration depending on the operation involved in the construction process. According to Wiss (1981), the vibration generated by construction sources is of a character that may potentially affect residents. As for railways, construction vibration is generated externally to the living environment but it has a transitory character.

In order to assess exposure and annoyance it is important to consider the size of the construction site and the duration of the work to ensure that a large sample of the residents should potentially be affected by the vibration. For this reason the operations from light-railway construction has been chosen as sources for determining the exposure in the living environment.

This specific source consists of a set of operations that are carried out in sections along a line. When the section is complete the vibration source moves to another point along the line. Logistically, the approach used for railway (the social survey must be conducted before the vibration measurements in order to avoid biased responses) cannot be adopted: but for transient sources, the survey must take place after the exposure has occurred by which time, the source of vibration has already moved on and internal measurements are no longer possible.

In this scenario the social and vibration teams worked independently. The response measurements were undertaken along the parts of the line where the activity was already finished, whereas the exposure was measured before, during and after the work with the assumption that the same exposure would occur at the other point of the line.

The methodology for the determination of the exposure is based on long term monitoring (or the control position, red dot in Figure 3) as close as possible to the boundary between the construction yard and the residential environment for recording the entire life cycle of the construction operations which required 62 and 37 days respectively on two different sites.

Controlled experiments based on array measurements (yellow dots in Figure 3) have been used for quantifying the attenuation of the vibration exposure across the residential environment caused by, according with the construction manager, the major activity of the construction operation. During the controlled experiment, a few internal measurements (orange dot in Figure 3) were taken for evaluating the internal exposure for the property types present in the residential environment.

The exposure recorded at the control position was propagated to other positions using the semi empirical propagation relationship with the attenuation parameter obtained in the controlled experiment.

Unlike the railway case the daily exposure from construction has been quantified over the duration of the works, i.e. between 8 a.m. and 6 p.m. and not over 24 hours.

Since the exposure from construction activity is a combination of the exposures from different operations, the maximum daily exposure occurring during the construction works has been used to quantify the exposure. An alternative approach would be to define a cumulative exposure over the entire duration of the works.

### Exposure from internal activity

Internal sources were defined as the set of vibration sources acting inside the residential property, such as those that are caused by mechanical excitation like washing machines or by human activity itself providing either continuous or transitory types of vibration.

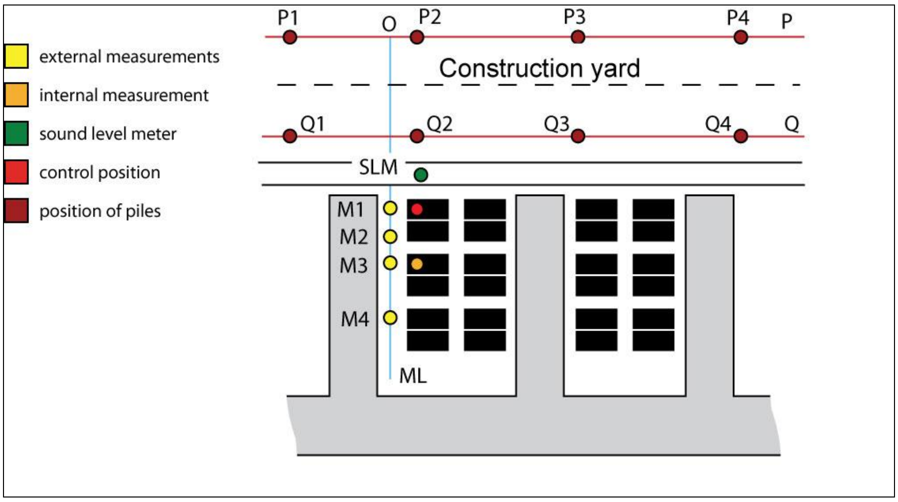


**Figure 3:** Overview construction site

The possibility that internal sources can be felt by residents is given by a combination of factors related to the frequency source and the resonance frequency and damping of the structural elements that propagate the vibration through the building. For these reasons, it seems that this problem is likely to be felt in high rise building or 'lively buildings' (Sylvestre-Williams et al. 2010).

Due to privacy issues it was not possible to gain access to 'lively building's therefore the measurements were performed where permission was available including university accommodation and sheltered accommodation managed by local authorities.

In this case the coordination between the social and vibration teams was similar to that for the railway case. The exposure measurement relies on synchronized long term monitoring (24 hours) in different parts of the building. Ideally the measurements were conducted in empty apartments to ensure that the living environment received only vibration from its surroundings. The exposure is calculated over the long term monitoring period.

## RESULTS

In this section some results of the exposure estimation for the source specific methodologies are presented.

In the railway case an estimation of the internal exposure is obtained for each case study providing a "one to one" relationship with the annoyance. Therefore, the direct consequence of this method is the exposure response relationship for the population affected by railway vibration reported in Woodcock et al. (2011).

The methodology used for construction vibration relies on a semi empirical attenuation-distance relationship of the vibration exposure across the living environment. In Figure 4 the decay with the distance of the total external vibration exposure expressed in VDV (z component $W_b$ weighting) is shown for the two construction sites used in our study.

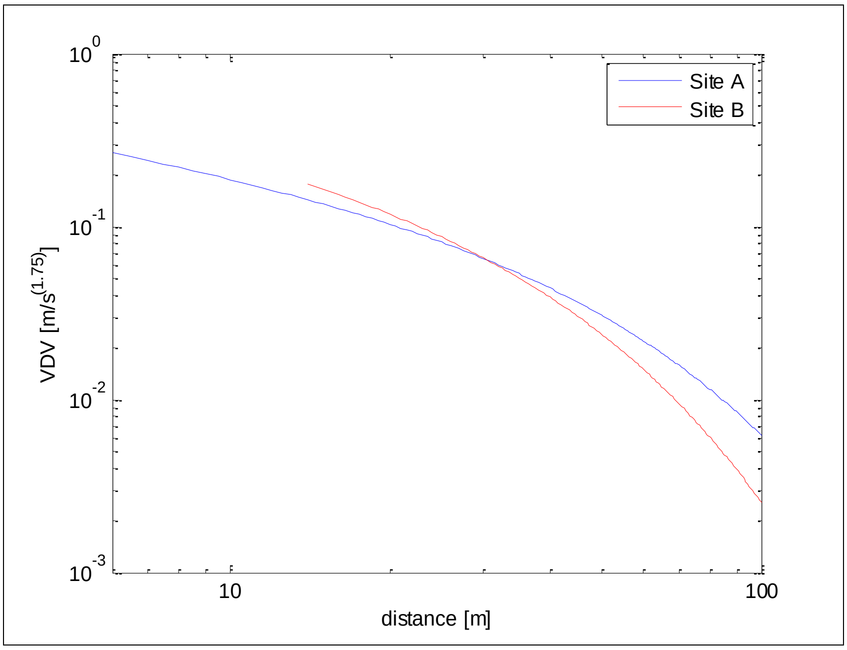


**Figure 4:** VDV (z component) vs distance. Total external exposure propagated from the long term monitoring position. Site A (blue line) exposure calculated over 62 days. Site B (red line) exposure calculated over 37 days. Graph in logarithmic scale

For internal sources, the procedure estimated the exposure from long term 24 hour internal measurements in different parts of the building considered for the study. In Table 1 the level of exposure expressed in VDV (z component $W_b$ weighting) is reported for the different floors of a university accommodation block. The difference in exposure between the ground floor and the other floors can be linked to the fact that the ground floor is the entrance of the building, so it might be possible that the amount of internal vibrations generated, for example by footsteps and door slams, are higher in comparison with the other floors of the building.

**Table 1:** VDV (z component) vs floor. Exposure calculated over 24 hours

| Floor | VDV |
|---|---|
| G. Floor | 0.3 |
| 1st Floor | 0.025 |
| 2nd Floor | 0.027 |

## CONCLUSION

Different methodologies for estimating the exposure from vibration sources in residential environments have been presented, suitable for providing data for deriving exposure response relationships. The different nature of the source considered (railway, construction and internal activity) required distinct strategies for measurement and estimation of the exposure, but also a different coordination was needed between the teams in charge of measuring both the exposure and the response.

The quasi static nature of railway activity has permitted synchronization with the social survey, and a large number of internal measurements have been collected. The methodology relies on a 24 hour long term measuring position and synchronized snapshot measurement within the respondent's property. The average velocity ratio between the two measurement positions has been used for scaling the activity recorded at the control position inside the property, so an estimation of the internal 24 hours exposure is obtained. Furthermore, the high proportion of internal measurements (53 % of 931 case studies) has also permitted estimation of the exposure for the case studies where it was no internal measurement was possible.

Unlike railway vibration, an intensive survey of internal measurements was not possible for construction activity, due to its transitory nature. The survey has been conducted using light railway construction works which has the advantage that essentially the same operations are repeated along the length of the track, thereby causing similar vibration exposure in a variety of residential areas. In this scenario, the social and vibration teams worked independently. The estimation of the exposure for construction relies on external measurements in an array configuration supported by a semi empirical prediction model for propagation of the measured exposure from the long term monitoring position, placed at the boundary between the construction yard and the living environment, to residences at different distances.

Internal sources are identified as the mechanical and human excitation created inside the property. They can be transitory or static depending on the nature of the excitation. It is common thinking that annoyance from internal sources is most evident in 'lively' buildings. However, residential buildings of this type were not accessible for the survey. The latter concentrated on university and sheltered accommodation where easy access was possible. The coordination among the teams was the same as for the railway case, and the estimation of the exposure is based on long term internal measurements on each floor of the building.

## ACKNOWLEDGMENTS

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# Socio-acoustic survey data archives at INCE/J

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## INTRODUCTION

While large numbers of social surveys on community response to noise, such as neighbourhood, road traffic, railway, and aircraft noises, have been carried out in Japan, the survey data has been left unused after their primary analyses. As a result, Japan Government faces many difficulties in reviewing noise policy and creating effective measures. To solve the problem, it must be important to provide infrastructure in which micro data, pairs of reactions and exposures associated with noise, are accumulated and maintained for promoting re-analysis. This means it is absolutely essential to construct data archive on socio-acoustic survey.

The application of the data archive provides for the research focusing on the different view point from the original. It is expected that studies regarding effects of non-acoustic factors (e.g. demographic factors, living environments, and vibration exposure) on reactions to noise and temporal social responses to noise are advanced. In addition, the accumulation of surveyed data under various circumstances makes it possible to present representative dose-response curves according to noise sources, in terms of annoyance, disturbances, and health effects. These findings contribute to the planning of effective noise policy based on public awareness.

The Institute of Noise Control Engineering/Japan (INCE/J) set up the Social Survey Data Archive Committee in 2009 for the purpose of developing an archive of social survey data on reactions to noise. By summarizing the results that have been achieved, the committee established the Socio-Acoustic Survey Data Archive (SASDA) in 2011. The archive is consisted of the micro data that the committee members deposited.

This paper summarizes the procedure operating (deposit, access, publication, maintenance) in the archive. Furthermore, by using the SASDA data, we made the secondary analyses of the reactions to noises. For one thing, we compared the dose-response relationships among road traffic, conventional railway, and Shinkansen railway noises. In addition, we examined whether non-acoustic factors affected community response to noise or not.

## OUTLINES OF SASDA

The committee set rules and procedures for managing SASDA, referring those of the Social Science Japan Data Archive (SSJDA) established at the Institute of Social Science, University of Tokyo. The operational procedure flow chart is shown in Figure 1.

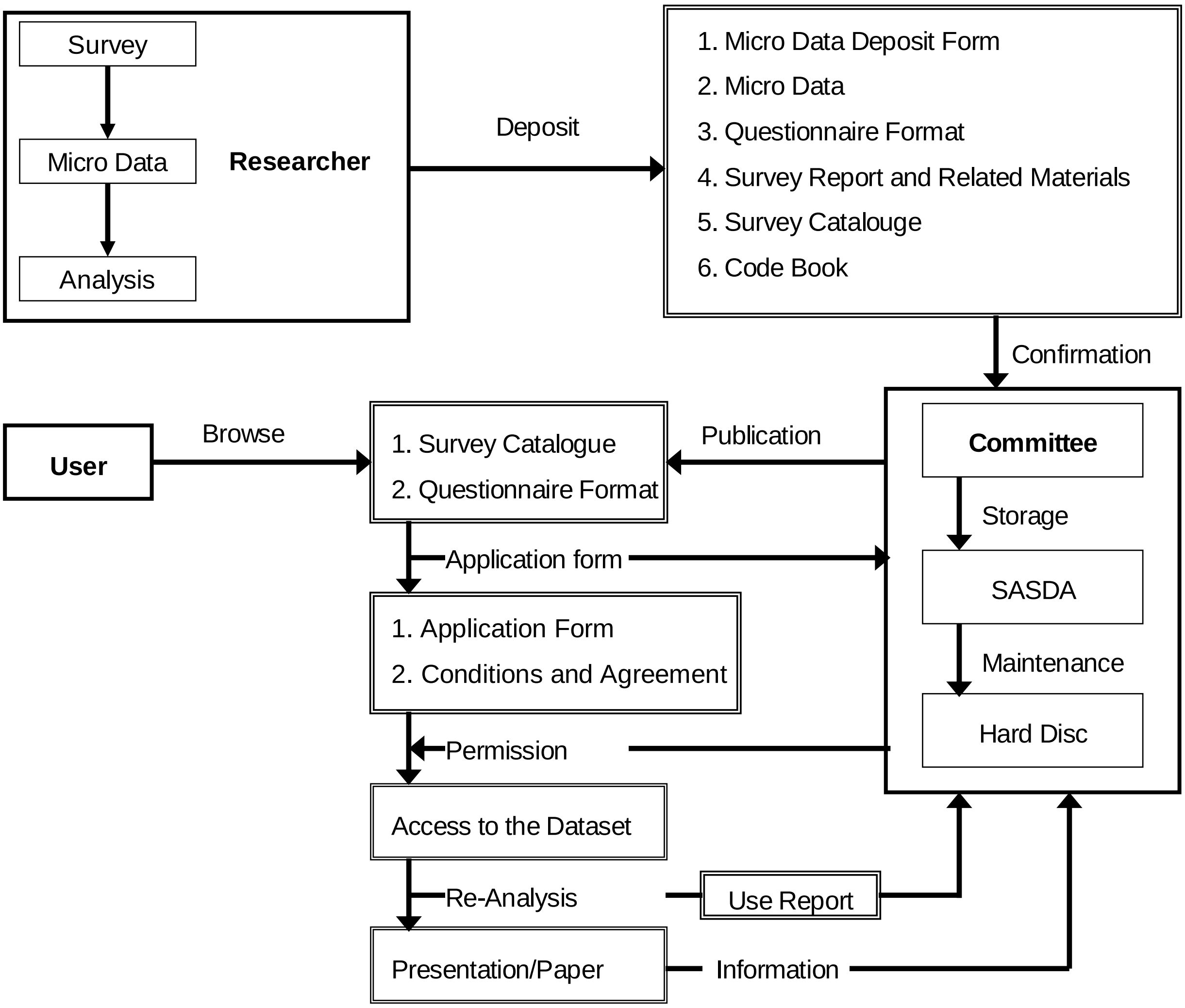


**Figure 1:** Operational procedure flow chart

### Deposit

At present, the archived data are largely deposited by the committee members. To increase micro data, we have to encourage other organizations and researchers to make their own data available to the public.

When researchers deposit their surveyed data to SASDA, they are required for the submission of the following materials: micro data deposit form, micro data, questionnaire form, code book, survey report (or paper regarding the research), and survey catalogue.

It is noted that materials (photograph and map related to survey) which could contribute to disclosing personal information are prohibited to the archive. Since the materials yield valuable clues of detail information on social surveys, the storage in a safe place plays an important role for SADA in preventing the materials from disappearing. Although it is important to archive photographs and maps relevant to survey, SASDA takes priority in protecting personal information and has a policy not to receive the materials.

However, the storage of information about the distance from noise sources to respondent's dwellings is allowed in the archive, unless information on survey sites is not disclosed. Information on the distance can be a moderator exploring factors affecting reactions to noise. Moreover, detail measurements (each noise level from passing trains, hourly noise level, etc) have the potential to be useful information to review noise metric. Thus, the committee encourages researchers to deposit the detail measurements if possible.

## Publication

The survey catalogue and questionnaire out of the deposited materials (only in Japanese) are published on the INCE/J homepage. Furthermore, relevant forms are available for download. Six items included in a survey catalogue are shown in Figure 2. Accordingly, applicants who wish to analyze datasets can browse survey catalogues on the website and obtain information on deposited researches.

**A. Survey purpose**

**B. Outline of survey**

1) Survey period
2) Survey site location (Local government of research sites)
3) Survey method (Face to face, Self-administered, Telephone, etc)
4) Outline of survey site (Site selection, Site size, Number of sites, etc)
5) Research institute
6) Outline of questionnaire (Title, number of question items, Number of pages)
7) Key questions (Exact wording of primary questionnaire items and answer alternatives)

**C. Respondent**

1) Conditions for respondents
2) Extraction of respondents from their own families
3) Number of distribution and respondents

**D. Estimaiton of exposures**

Items for road traffic, railway and environment noises are indicate below.

1) Noise metrics
2) Estimation method for noise exposure
3) Noise source
4) Measurement institute
5) Noise measured quantity
6) Measuring points
7) Measurement procedure
8) Calculation of noise metrics at the measuring points
9) Estimation of noise mertics to respondents

**E. Special instructions**

1) Non-acoustical effect (measurement of vibration, low-frequency noise, air-pollution,etc)
2) Presence or absence of detailed measurements

**F. Conference presentations and papers**

Paper with or without peer review

**Figure 2:** Outline of survey catalogue

## Access

The methods of data access permit show by a run of the item.

- Members of INCE/J or ASJ (Acoustic Society of Japan) are allowed access to datasets at the archive.
- In addition, depositors of SASDA are also allowed access to the datasets.
- Graduates or undergraduates whom the above qualified persons instruct are available for access.
- When users wish to analyze a particular set of archived data, they are obliged to submit the Data Application Form to the committee.
- Users shall restrict their use of the data to secondary analysis for research purposes only.
- Users shall agree that the depositors of the data and SASDA bear no responsibility for any disadvantage they might encounter as a result of using the datasets supplied by SASDA.
- Data access permit is required with the depositor's permission.
- All inquiries regarding the surveys are made, in principle, through the SASDA, and not directly to depositors.
- Data access permit period is one year. If users are unable to complete the data analysis within the one year permit period, they may apply for an extension of the permit, by submitting a new application form to SASDA.
- Upon termination of the data access permit period, users shall erase the datasets.
- The cost of access to the dataset is free of charge.
- When publishing the results of the secondary analysis of SASDA datasets, users shall acknowledge the data source.
- Users shall also submit to SASDA the Data Use Report Form.
- Users shall comply with all other requirements specified by SASDA.

## Maintenance

To protect the disappearance and leaks of archived data, all the micro data are stored at four external hard disk drives (data mirroring). Each set of two drives is maintained at separate places. Furthermore, the committee has the latest virus protection software installed on its computers for increasing security. However, during the task, archiving datasets and writing datasets to which an applicant permits access into a media (CD-R), the committee shall work off-line without loose ends to protect the leaks on the Internet.

## Archived datasets

The list of deposited datasets is indicated in Table 1. Diverse institutes have cooperated the archive. The number of archived researches is 23 and collected micro data amounted to about 20,000. Since the committee has collected micro data which are mainly stored as electric files, researches since the 1990s have been mainly collected. By noise sources, SASDA holds sufficient researches on road traffic and railway noises. On the contrary, very few researches on aircraft noise and combined are available for secondary analysis. In addition, no survey on health impact of noise is archived.

**Table 1:** List of SASDA

| ID | Noise | Survey Period | Survey Area | Research Institute |
|---|---|---|---|---|
| S1 | Personal Exposure Noise | 1975－1978 | Nagoya City, etc. | Nagoya Univ. |
| S2 | Environmental Noise | 1982－1994 | Nagoya City | Nagoya Univ.<br>Daido Univ. |
| S3 | Conventinal Railway Noise | 1994－1995 | Fukuoka Pref.<br>Kumamoto Pref. | Kumamoto Univ. |
| S4 | Road Traffic Noise<br>(Highway Road) | 1994－1995 | Kumamoto Pref. | Kumamoto Univ. |
| S5 | Shinkansen Railway Noise | 1995－1996 | Kanagawa Pref. | Yokohama Nat. Univ.<br>Kanagawa Pref. Govt. |
| S6 | Road Traffic Noise | 1996 | Kumamoto City | Kumamoto Univ. |
| S7 | Conventional Railway Noise | 1997 | Kanagawa Pref. | Yokohama Nat. Univ.<br>Kanagawa Pref. Govt. |
| S8 | Road traffic Noise | 1997－1998 | Sapporo City | Hokkai-Gakuen Univ. |
| S9 | Road Traffic Noise | 1997－1998 | Bangkok City | Kumamoto Univ.<br>Suranaree Univ. of Tech. |
| S10 | Road Traffic Noise | 1998 | Kanagawa Pref. | Yokohama Nat. Univ.<br>Kanagawa Pref. Govt. |
| S11 | Road Traffic Noise | 1999－2000 | Kanagawa Pref. | Yokohama Nat. Univ.<br>Kanagawa Pref. Govt. |
| S12 | Road Traffic Noise | 2000－2002 | Chiba City, etc. | Ministry of the Environment<br>INCE/J |
| S13 | Conventional Railway Noise | 2001 | Sapporo City, etc | Hokkai-Gakuen Univ. |
| S14 | Shinkansen Railway Noise | 2001－2003 | Kanagawa Pref. | Yokohama Nat. Univ.<br>Kanagawa Pref. Govt. |
| S15 | Conventional Railway Noise | 2002 | Osaka City | Osaka City |
| S16 | Conventional Railway Noise | 2002 | Fukuoka Pref. | Kumamoto Univ. |
| S17 | Shinkansen Railway Noise | 2003 | Fukuoka Pref. | Kumamoto Univ. |
| S18 | Road Traffic Noise | 2003－2004 | Tomakomai City | Hokkai-Gakuen Univ. |
| S19 | Conventional Railway Noise | 2003－2004 | Chiba City, etc. | Ministry of the Environment<br>INCE/J |
| S20 | Combined Noise | 2004－2006 | Kanagawa Pref. | Yokohama Nat. Univ.<br>Kanagawa Pref. Govt. |
| S21 | Shinkansen Railway Noise | 2005 | Nagoya City | Aichi Inst. Tech., etc. |
| S22 | Aircraft Noise | 2006 | Kumamoto Pref. | Kumamoto Univ. |
| S23 | Conventional Railway Noise | 2007 | Osaka City | Osaka City Univ. |

## SECONDARY ANALYSIS

Using 17 datasets archived at SASDA, we tried to make secondary analysis. Table 2 indicates information on noise exposures, distance from noise source to respondent's dwelling, and responses (annoyance and traffic access) of the analyzed datasets. Whereas all the surveys estimated 24-hour $L_{Aeq}$, about half of the surveys provided $L_{dn}$. Thus, this study uses 24-hour $L_{Aeq}$ as noise exposure metric.

As shown in Table 2, annoyance is evaluated from 4-point to 7-point scales. Moreover, the wording of question and answer alternatives with respect to annoyance differed among the surveys. However, a majority of recent researches measures annoyance by ICBEN verbal scale. For the distance, not all dataset included the information. In contrast, evaluation of traffic access was obtained for all the surveys.

**Table 2:** Information on the analyzed datasets

| Survey ID | $L_{Aeq}$ | $L_{dn}$ | Distance | Annoyance | Traffic access |
|---|---|---|---|---|---|
| A | 1 | 1 | 0 | 4-point | 2-point |
| B | 1 | 1 | 0 | 4-point, 5-point, 6-point, 7-point | 5-point |
| C | 1 | 1 | 0 | 4-point | 5-point |
| D | 1 | 0 | 1 | 5-point | 4-point |
| E | 1 | 1 | 0 | 4-point | 5-point |
| F | 1 | 0 | 1 | 5-point | 4-point |
| G | 1 | 1 | 1 | 4-point | 5-point |
| H | 1 | 0 | 1 | 5-point | 4-point |
| I | 1 | 0 | 0 | 5-point | 5-point |
| J | 1 | 1 | 1 | 4-point, 5-point | 5-point |
| K | 1 | 0 | 1 | 5-point | 5-point |
| L | 1 | 1 | 1 | 5-point | 5-point |
| M | 1 | 0 | 1 | 5-point | 5-point |
| N | 1 | 1 | 0 | 5-point | 5-point |
| P | 1 | 0 | 1 | 5-point | 5-point |
| 0 | 1 | 1 | 1 | 5-point | 5-point |
| Q | 1 | 0 | 1 | 5-point | 5-point |

0: not including, 1: including

To uniform the scale for annoyance, % highly annoyed (%HA) is defined as shown in Figure 3. For 4-point and 5-point scales, %HA is defined as the ratio of the top category answer.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4-point scale | 1 | 2 | 3 | **4** | | | |
| 5-point scale | 1 | 2 | 3 | 4 | **5** | | |
| 6-point scale | 1 | 2 | 3 | 4 | **5** | **6** | |
| 7-point scale | 1 | 2 | 3 | 4 | 5 | **6** | **7** |

**Figure 3:** Definition of % highly annoyed

Figure 4 compares dose-response curves for annoyance among noise sources (road traffic, conventional railway, Shinkansen Railway, and environment noises). The curves are determined using nominal logistic regression analysis. This figure indicates the annoyance due to noise from the Shinkansen is most severe as the previous studies reported (Tamura 1994; Yokoshima & Tamura 2003; Yano et al. 2005). On the other hand, %HA for conventional railway noise is higher than that for road traffic noise. In Euro-American surveys it has been frequently shown that railway noise is less annoying than road traffic noise (Miedema & Voss 1998). In contrast, recent studies carried out in Japan have not clarified railway bonus as the same result shown in this figure (Morihara et al. 2004).

Figure 5 compares dose-response curves for annoyance according to the distance from the noise source to dwelling (≤50 m and >50 m), using logistic regression analysis. This analysis ignores the difference in annoyance among the sources. This figure indicates people who are closer to the noise source are more annoyed. The difference can be explained synergetic effect of ground vibration on noise annoyance. In addition, dwelling adjacency to noise sources may be contributed to the difference in railway bonus between in Europe and Japan.

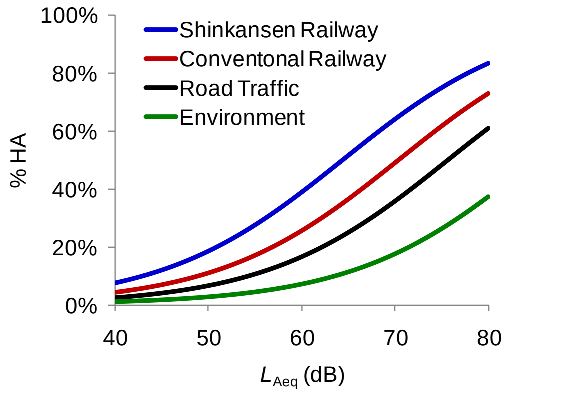


**Figure 4:** Comparison of dose-response curves among noise sources

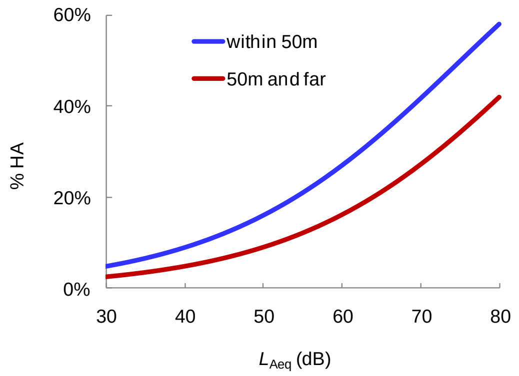


**Figure 5:** Comparison of dose-response curves according to the distance

Figure 6 compares dose-response curves for annoyance between the groups by the evaluation to traffic access. Likewise for Figure 5, all the data integrated regardless of the noise sources are analyzed. 4-point and 5-point scales of the evaluation are converted into 2-point scales: convenience and inconvenience. The curve of convenience indicates higher annoyance than that of inconvenience. This suggests that the convenience of traffic access reduces the annoyance. It is probably difficult that such an analysis is made using data obtained from a social survey, because the evaluation of traffic access frequently becomes one-sided.

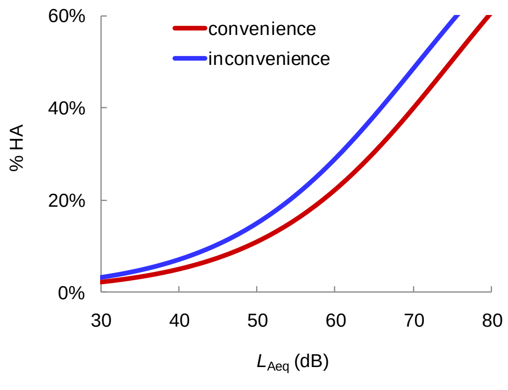


**Figure 6:** Comparison of dose-response curves by the evaluation of traffic access

## ACKNOWLEDGMENTS

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# The DEBATS Study: Health effects of aircraft noise near three French airports

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## INTRODUCTION

A national survey carried out in 2005 by INRETS[4] (French National Institute for Transport and Safety Research) shows that 6.6% of the French population is annoyed by aircraft noise (Lambert & Philipps-Bertin 2009). While many surveys carried out both in France and abroad address aircraft noise annoyance (Vallet & Cohen 2000; Bristow et al. 2004; Schreckenberg et al. 2009) or report adverse effects on sleep quality (Stansfeld et al. 2000; Hume et al. 2003; Franssen et al. 2004; Griefahn et al. 2004; Lainey et al. 2004; Muzet 2007; Basner et al. 2008), much fewer consider at the same time the physiological effects of this noise exposure. The largest study to date is the HYENA study (HYpertension and Exposure to Noise near Airports). This study has evidenced an association between aircraft noise exposure and hypertension (Jarup et al. 2008).

## OBJECTIVES

DEBATS aims to characterize the relations between aircraft noise exposure and health status of the French population living in the vicinity of airports, both physically and mentally but also in terms of annoyance.

## METHODS

DEBATS is an on-going research program (2011-2016) involving residents around three French airports: Paris-Charles de Gaulle, Toulouse-Blagnac, and Lyon Saint-Exupéry. It includes three studies corresponding to three methodological approaches: an ecological study, a longitudinal field study and a complementary clinical study. The results of these studies will be complementary, enabling to cross-check any statistical associations.

The objective of the ecological study is to investigate the relationship between average aircraft noise exposure and drug prescriptions, nonprescription drug sales or mortality at the *commune* (the smallest administrative unit in France) level.

The longitudinal field study consists in following-up approximately 1,200 of the above-mentioned airports residents during four years. This study addresses the existence of a link between aircraft noise exposure and the measurements of different parameters related to health. In particular, annoyance and health status (current and

[4] INRETS became IFSTTAR (French institute of science and technology for transport, development and networks) on the first of January 2011.

past) are assessed by questionnaires. Physiological variables like blood-pressure or salivary cortisol are also considered within the frame of this study.

In both ecological and longitudinal studies, aircraft noise exposure will be estimated using noise maps. Residents living near France's largest airports can receive grants for soundproofing their homes. To determine which residents are eligible for this funding, a noise exposure map has been drawn up for each of these airports. These maps are based on estimated air traffic, applicable air traffic control procedures and infrastructures that will be in use in the year following the date of publication of the order approving the map. They consist of three areas (Cf. Figure 1): the first one indicates a very high level of noise pollution limited by the $L_{den}$ 70 index curve; the second one indicates a high level of noise pollution between the $L_{den}$ 70 and $L_{den}$ 65 index curves; and the last one indicates a moderate level of noise pollution between the $L_{den}$ 65 and $L_{den}$ 55 index curves. Within the frame of DEBATS, the French Civil Aviation Authority has assessed a fourth area which indicates a low level of noise pollution between the $L_{den}$ 55 and Lden 50 index curves.

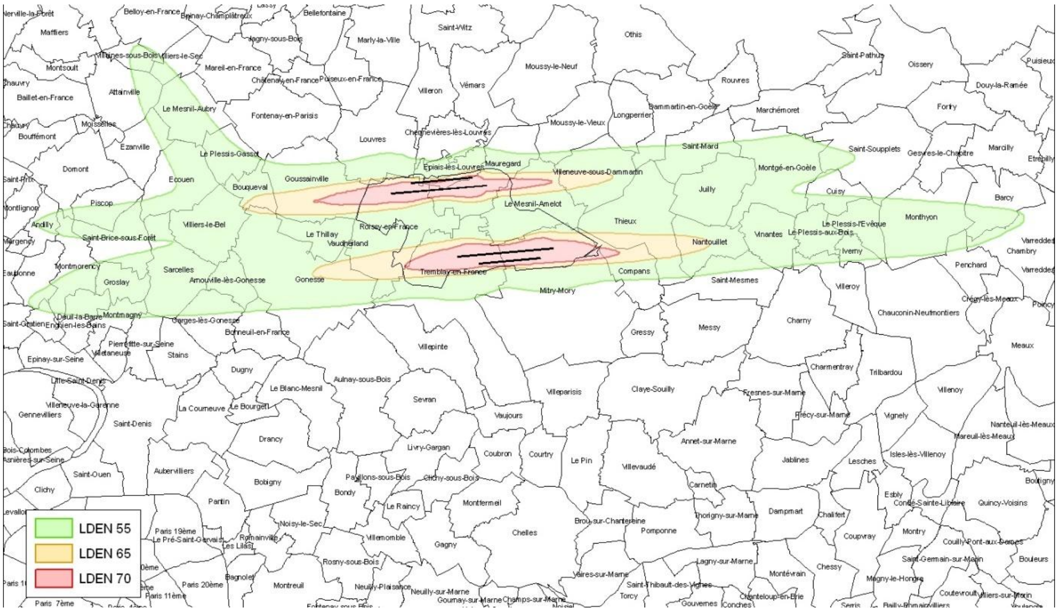


**Figure 1:** Paris-Charles de Gaulle airport noise exposure map

The complementary study aims to characterize specifically and in detail acute effects of aircraft noise on sleep quality using precise noise exposure measurements. This study will be carried out on a sub-sample of 100 individuals included in the longitudinal study. Sleep quality will be evaluated using a wrist actimeter: the subjects will wear it for seven nights. Simultaneously, a sonometer located in their bedroom will register their noise exposure during these nights. A second sonometer set up outside (at the bedroom façade) will allow us to identify the aircraft noises and to investigate a link with sleep quality.

A pilot study will take place at the end of 2011 in order to test and validate the protocols of the longitudinal and complementary studies on 100 residents around Paris-Charles de Gaulle airport.

## EXPECTED RESULTS

This project will support the development of public prevention policies of health risks. While contributing to a wider and deeper knowledge of the French sanitary situation resulting from aircraft noise exposure, DEBATS will make it possible to assess the expected health benefits of the implementation of aircraft noise abatement policies around airports.

## ACKNOWLEDGEMENTS

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# Effects of nocturnal railway noise on annoyance: Dose-response relationships from a field study in comparison to nocturnal aircraft noise annoyance

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## INTRODUCTION

Traffic noise exposure during the night may disturb sleep and recreation inducing possible annoyance reactions of affected residents. Significant dose-response relationships between nocturnal aircraft noise and annoyance were confirmed, for instance, in a laboratory and a field study conducted by the DLR Institute of Aerospace Medicine (Quehl & Basner 2006). A common finding of studies on annoyance comparing different traffic modes is that annoyance ratings increase in the order railway least, road, and aircraft most (Miedema & Oudshoorn 2001; Miedema & Vos 1998). Based on these dose-response relationships a railway bonus was adopted in several European countries. The low impact of railway noise, however, was challenged by current investigations leading to the recommendation that the “rail bonus issue” has to be studied further (Gjestland 2008). In a recent laboratory study the effects of different traffic noise sources were compared with respect to sleep disturbance and annoyance (Basner et al. 2008). Although sleep disturbance increased in the order air, road, and rail traffic, it was found that annoyance reactions due to railway and road noise were equal and strongest due to aircraft noise. Since the validity of laboratory findings has to be proved in field studies the current study investigated the effects of nocturnal railway noise on sleep and annoyance of residents living in the vicinity of railway tracks in Germany. The present paper is focusing on annoyance and aims to compare the findings to the results of our field study on aircraft noise annoyance (Quehl & Basner 2006) providing a ranking of the two traffic modes with regard to night time noise annoyance.

## METHODS

For the investigation of railway noise those railway lines of the Cologne/Bonn area were selected that bear a large quantity of freight train traffic during the night and where at the same time low road traffic was observed around. 33 subjects (22 women and 11 men) between 22 and 68 years (*M* = 36.2, *SD* = 10.3) participated in the field study. They lived between 0.7 and 29.6 years (*M* = 5.5 years, *SD* = 6.0) in their residences near the railway lines. During the daytime participants followed their normal course of life and could choose their bedtime individually with a compulsory sleep period between midnight and 6 a.m.

Acoustical measurements were carried out during nine consecutive nights at each site. Noise exposure was recorded indoors at the sleepers’ ears by class-1-sound level meters (NC10, Cortex Instruments). The A-weighted energy equivalent noise level ($L_{Aeq}$) and number of noise events (total number of trains, freight trains, and passenger trains) during bed time of each participant and each night were calculated.

Subjects rated annoyance due to nocturnal railway noise exposure in the morning by a questionnaire. A five-point scale ranging from 1 = ”not” to 5 = ”very” was used. Additionally, general annoyance previous to the study without referring to a special time of day and non-acoustical factors which could influence annoyance were evaluated by the participants once on five-point scales.

The results were compared with the results of a field study on aircraft noise which was conducted using identical methods in the vicinity of Cologne/Bonn Airport, an airport with high cargo traffic during the night (Quehl & Basner 2006). In that study 64 subjects (35 women and 29 men, mean age 37.4 years, *SD* = 12.7) were investigated.

RESULTS

General annoyance ratings previous to the study showed that more than half of the subjects (54 %) were highly annoyed (categories 4 and 5). With respect to nocturnal annoyance, however, which was evaluated every morning the percentage of all annoyance ratings in these categories covered only 2 %. Therefore, the analysis of dose-response relationships was based on the combination of ratings from moderate to high annoyance (categories 3-5) to a dichotomous dependent variable.

Dose-response relationships were established between nocturnal annoyance and the railway noise indicators $L_{Aeq}$ and number of noise events (number of trains in general, freight trains, and passenger trains). For each of these acoustical variables a specific model using logistic regression analysis was calculated. No significant dose-response relationships were proved when only the acoustical variables were taken into account. Thus, non-acoustical factors were included in the model and the variables with the lowest impact were removed by a stepwise backward procedure. The final models were adjusted for subjective adaptation and length of residence. Again, annoyance increased only non-significantly, with rising $L_{Aeq}$ ($\beta$ = .021, *SE* = .038, *p* = .584). For the number of trains, however, a significant dose-response-relationship could be demonstrated ($\beta$ = .021, *SE* = .009, *p* = .018). Furthermore, nocturnal annoyance rose significantly with growing numbers of freight trains ($\beta$ = .020, *SE* = .010, *p* = .048), but not with passenger trains. Here just a trend was seen ($\beta$ = .044, *SE* = .024, *p* = .067). With regard to the non-acoustical variables subjects who stated that they could better adapt to railway noise were less annoyed ($p<0.001$). Annoyance increased with longer time of residence nearby the railway lines ($p<0.05$).

The data of the field study on railway noise annoyance were compared to the findings of the field study on aircraft noise annoyance (Quehl & Basner 2006) in one logistic regression model. Based on the significant dose-response relationships calculated for aircraft noise annoyance the number of noise events per night (overflights respectively total number of trains) and the A-weighted energy equivalent noise level $L_{Aeq,\ event}$ measured indoors during bed time, where only those noise events exceeding 35 dBA had been taken into account were considered as noise indicators. In order to demonstrate a direct comparison between the effects of aircraft and railway noise only the acoustical factors without moderating variables were integrated in the regression models calculated for each indicator.

The results show that annoyance due to aircraft noise increased significantly with rising values of $L_{Aeq,\ event}$ ($p$<0.001) whereas the effect of railway noise on annoyance was smaller and not significant ($p$=0.65). Dose-response relationships based on predicted values from the regression model (Figure 1) indicate that annoyance is higher due to aircraft noise than due to railway noise. For example, the percentage of persons highly and moderately annoyed grew from a small percentage of approximately 4 % at 20 dB(A) to more than 40 % at the maximum of nearly 50 dBA for aircraft noise. The rise of annoyance due to railway noise, however, is hardly noticeable in the dose-response curve.

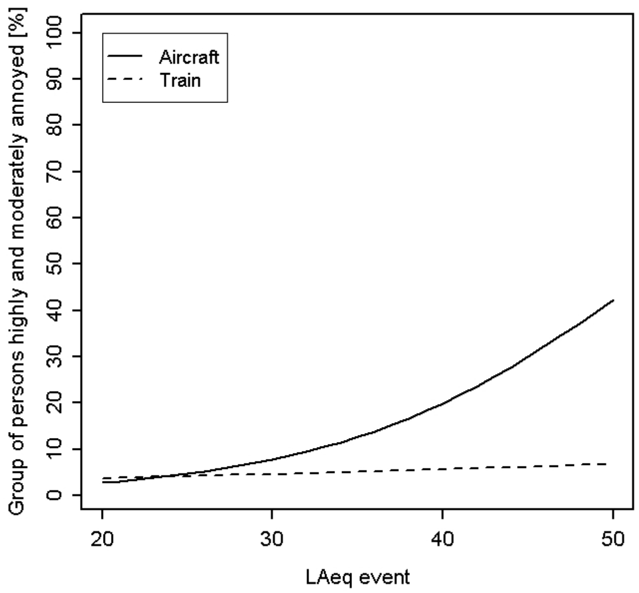


**Figure 1:** Predicted percentage of persons highly and moderately annoyed (categories ≥ 3) by aircraft and railway noise depending on the energy equivalent noise level $L_{Aeq\ event}$

Figure 2 illustrates the percentage of highly and moderately annoyed subjects depending on the number of noise events (nocturnal flyovers respectively trains). Annoyance due to aircraft noise increased significantly with rising number of noise events ($p$<0.001), and in this model non-significantly due to railway noise ($p$ = .15). The dose-response curves show that annoyance due to aircraft and railway noise increased similarly up to 40 noise events per night. The percentage of persons annoyed by aircraft noise, however, rose up to about 68 % at the maximum number of flyovers of nearly 140. With the same number of trains the proportion of persons annoyed by railway noise was 18 % indicating a maximum difference of nearly 50 %. At 100 noise events per night, for instance, the percentage of people annoyed by nocturnal aircraft noise as predicted by the logistic regression model was over 30 % compared to approximately 10 % annoyed by the same number of trains. Furthermore, the curves for both railway noise indicators provide evidence for the higher relevance of number of trains compared to the energy equivalent noise level as shown in the regression models for railway noise alone.

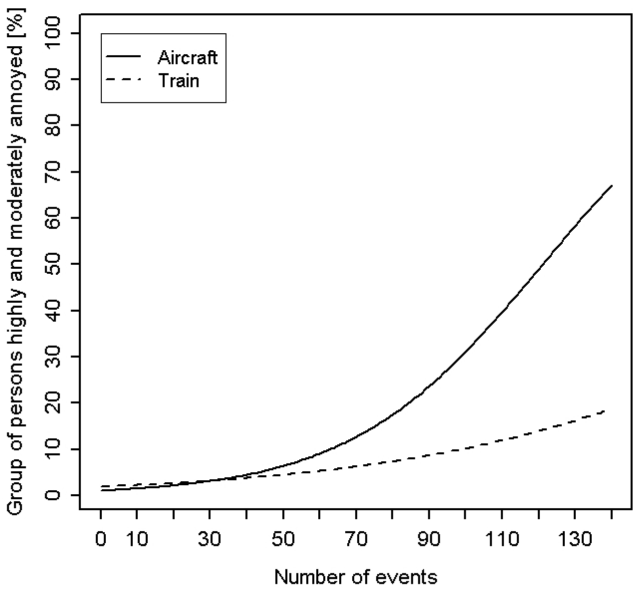


**Figure 2:** Predicted percentage of persons highly and moderately annoyed (categories ≥ 3) by aircraft and railway noise depending on the number of noise events

## CONCLUSIONS

Dose-response relationships between nocturnal railway noise and annoyance ratings showed a significant increase of annoyance with rising number of trains, particularly freight trains, only if the regression model was adjusted for moderating variables. Subjects were less annoyed by the measured energy equivalent sound pressure level, since no significant effect was found. Furthermore, the data suggest that general annoyance judgements are mainly based on annoyance from traffic noise exposure during the day. A comparison with the effects of aircraft noise indicates lower nocturnal annoyance from railway noise than from aircraft noise at the same number of noise events and the same $L_{Aeq,\ event}$ measured indoors during bed time. Thus, the combined results from these field studies support the common ranking of rail and aircraft traffic in European countries with respect to annoyance.

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**The final paper was not available at deadline.**

## A survey on reaction of noise and vibration in construction sites

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ABSTRACT

86 % of disputes related with noise and vibrations were mediated by Ministry of environment and over 61 % of construction sites have suffered with noise complaint. Most noise complaints of construction sites are caused by construction equipment. In some countries, there are regulations to control noise level of construction equipment. The regulations classify construction equipment by 2 categories which are equipment subject to noise limits and equipment subject to noise marking only. However those kinds of regulations have limitation to reduce construction site noise and vibrations because various construction equipment were normally operated in construction site at the same time. And there is no clear guide line to control overall construction site noise. In this study, occurrence frequency and types of noise and vibration from construction sites were evaluated and types of complaint and reactions were analyzed.

# Calculation of noise in residential environments

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## ABSTRACT

The DEFRA funded project "*Human Response to Vibration in Residential Environments*" investigates relationships between human response in residential areas, primarily in terms of annoyance, and combined effects from exposure to vibration and noise. This paper focuses on the results from the analysis of noise exposure in this study, in particular from construction work and railway traffic. The exposures for railway traffic noise sources were obtained and calculated according to a routine based on Calculation of Railway Noise(1) (Department of Transport 1995) and "Additional railway noise source terms for 'Calculation of Railway Noise (2007)'" (Department of Transport 2007). On the other hand, exposure from construction work was calculated based on measurements of the various sources at different locations. This paper compares noise exposures from those sources in terms of level of noise, frequency content, distance from source to receiver, and the environment in which residents are exposed to noise and the reported annoyance. To conclude, the paper shows the relationships between noise exposure from the different vibration sources and annoyance. [Work funded by the Department for Environment, Food and Rural Affairs (Defra) UK].

## INTRODUCTION

Environmental noise is the effect of single or combined sources generating sound. Noise exposure, affecting residential environments, has its source in railway, construction, aircraft traffic, and road traffic. Additional to the effects from different noise sources, residential environments are also exposed, to a greater or lesser extent, to vibration. This combination of exposures has already been investigated in Sweden in a similar project called TVANE (Öhrström et al. 2008). TVANE also analyzed similar problems regarding combination of noise and vibration. This project "*Human Response to Vibration in Residential Environments*", funded by Defra, also investigated combined effects of exposure to noise and vibration.

This paper outlines the process of calculation of noise exposure from different sources, such as railway traffic and construction work. Although some analysis regarding the exposure - response relationship has been included, the detailed information of this topic, regarding combined effects, can be found in Technical Report 6 "*Determination of Exposure-Response Relationships*" (Woodcock et al. 2011.)

## BACKGROUND

For the purposes of the project "*Human Response to vibration in residential environments*", all sites were carefully chosen to fulfill the main objectives, which were to measure vibration in the vicinity of railway and construction sources. A great number of vibration measurements were conducted around the Midlands and North-west of

[1] Calculation of Railway Noise (Department of Transport 1995) is denoted as CRN throughout this paper

England. On the other hand, measurement of construction sources took place in South and Site B. Measurements of construction activities covered a process of building new light railway in Manchester.

Variations were found in terms of the noise levels attributable to the different sources (construction and railway), although these variations were also observed in different locations of the same sources themselves.

This paper presents the outline of the results from the noise measurements. For the details regarding the measurement of vibration, calculation of noise, and determination of exposure-response relationship, it is suggested the technical reports published by Defra are read (Sica et al. 2011; Woodcock et al. 2011).

METHODOLOGY

## Noise metrics

To express an overall noise exposure over a 24 h time period, a noise descriptor such as $L_{den}$ has been chosen. It is defined in terms of average sound pressure level during daytime (07:00 - 19:00), evening (19:00 - 23:00) and night time (23:00 - 07:00) and imposes a 5 dB penalty during the evening and 10 dB penalty during the night time. $L_{den}$ is calculated from the following formula

$$L_{den} = 10\log_{10}\left(\frac{12\times 10^{L_{day}/10} + 4\times 10^{(L_{evening}+5)/10} + 8\times 10^{(L_{night}+10)/10}}{24}\right) \quad (1)$$

$L_{den}$ has been defined in the EC (Directive 2002/49/EC 2002) and adapted during investigation of exposure - response relationships in similar research (Miedema & Oudshoorn 2001; Miedema 2004; Miedema & Vos 1998).

In terms of railway traffic, noise exposure $L_{den}$ was obtained from CRN (Department of Transport 1995). On the other hand, noise exposure from construction activities was obtained from measurement of all possible sources during the daytime only. As such, an average $L_{Aeq,10h}$, has been used as a proxy for $L_{day}$, the exposure being assumed negligible in the remaining two hours of the day. The Code of Practice BS 5228-1:2009 (BSI 2009) was found to be helpful to develop a proper routine for determination of noise exposure from construction work. Additionally, an intermediate noise descriptor $L_{AE}$[(2)] was also applied due to its flexibility for calculation of overall noise level from a number of similar sources.

## Calculation of noise from railway sources

Although a few noise measurements have been conducted according to BS 7445-2:1991 (BSI 1991), noise exposure from railway traffic was obtained from calculation based on Calculation of Railway Noise (CRN).[(1)] This well-known Code of Practice provides a routine for determining noise exposure, covering a vast number of conditions. For predictive purposes, information about a number of passenger and freight trains were obtained from accelerometers, which monitored vibration for 24 hours

[2] Sound Exposure Level (abbreviated as $L_{AE}$ or SEL) applies to discrete noise events and is defined as the constant level that, if maintained during a 1 s interval, would deliver the same A-weighted sound energy to the receiver as the real-time varying event. It can be also understood as a $L_{Aeq,T}$ normalized for T = 1 s (Crocker 2007)

(see Figure 1). An algorithm, detecting the number of trains from vibration, has been applied in order to provide an estimation of railway traffic. The majority of measurements of vibration involved more than one accelerometer per site. Therefore an average number of train occurrences from all control positions was calculated. A detailed explanation has been included in Technical Report 3 (Sica et al. 2011).

CRN defines a routine covering all details influencing the final noise emission from vehicles passing by a point of reception. Additionally, CRN covers site topography, ground reflection, number of vehicles per train, number of trains per 24 h, air absorption (although this is primarily a high frequency effect), a distance correction, barrier attenuation, reflections from facades, and reflective contributions of buildings surrounding the point of reception. The most significant and accurate approach demands a great deal of specific and detailed information about sites which were not available.

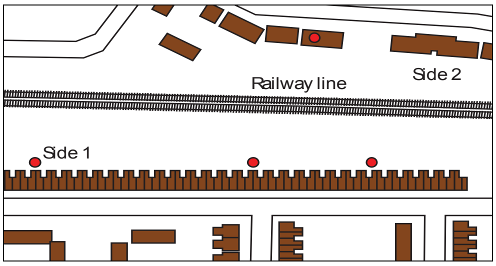


**Figure 1:** Plan view of one of the sites where vibration measurements took place. Two sites are covered by the same rail line. Residents were exposed to vibration from the same rail line. Vibration was monitored for 24 h by all control positions, indicated by red spots.

Table 1 presents an example of the number of passenger and freight trains detected by the algorithm mentioned above.

**Table 1:** Example of estimating the number of passenger and freight trains on a site

| | Day | Evening | Night |
|---|---|---|---|
| No of passenger trains | 117 | 40 | 23 |
| No of freight trains | 1 | 1 | 2 |

### Calculation of exposure to construction noise

The main difference for construction work relates to the character of the noise and its frequency content. On one hand, piling, as one of the main activities, has been found to be an impulsive and repetitive noise source. On the other hand, more uniformly distributed noise sources were found in Site B, including saw-cutting, flattening etc. Background noise level was significantly high to increase uncertainties during the measurements.

The concept of determination of exposure was similar to that for railway noise and the routine was based on the Code of Practice BS 5228-1:2009. Unlike CRN, noise exposure has been established according to $L_{AE}$ obtained from field work, where construction plants have been measured individually. According to BS 5228-1:2009, noise descriptors were normalized to a 10 m distance between the source and reception point. An equivalent-continuous sound pressure level $L_{Aeq,T}$ was adjusted to a

10 h period, which is similar to $L_{day,}$ a daytime average $L_{Aeq,T}$, yet does not always represent the same value[3]. Finally, all sources were logarithmically summed.

Different approaches to measurements were adopted in East and Site A due to limitations, mostly due to space. A more direct path was found in Site A though. In Site B, a SLM[(4)] was positioned in a free field (Figure 2, right pane) due to difficulties in obtaining access to private areas with façades.

In Site A (left pane of Figure 2), the SLM was installed about 15 m away from the sources, at a distance of 1 m from the most exposed façade and 1.5 m above ground level.

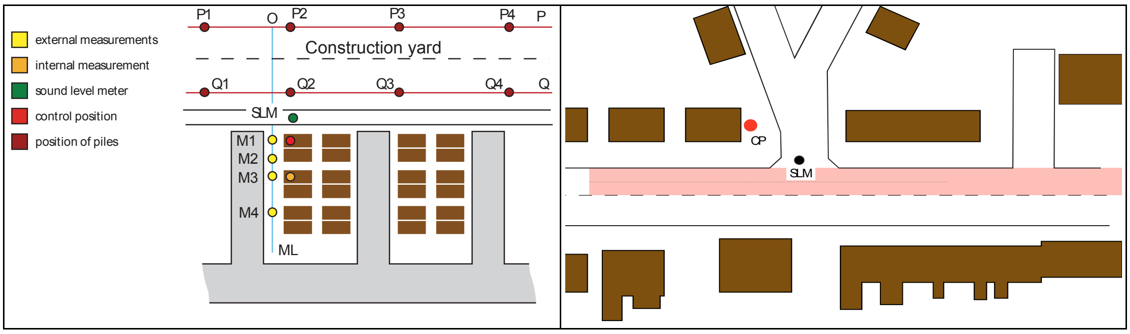


**Figure 2:** Plan view of two sites where vibration and noise measurements took place. Left pane: site in Site A, right pane: site in Site B

RESULTS

**Railway noise exposure**

This section presents an outline of the results from the calculation of the 24 h exposure to noise from railway traffic. For the purpose of this project, the exposure was quantified with $L_{den}$, which required a minor modification of the calculation routine given in CRN.

At the time of the measurements, there was a great variation in freight train occurrences. Additionally, freight trains were difficult to anticipate as they are not regularly scheduled, unlike passenger trains. There was also a limited number of dedicated rail lines along which freight trains are allowed to travel. Table 2 presents the results of the prediction obtained from the calculation based on the CRN.

The left hand-side graph in Figure 3 shows a comparison of the noise spectrum of a typical passenger train and a construction source both normalized to a 10m distance. It can be observed that higher frequency bands of the railway source contain much lower levels than the construction source.

The level of annoyance versus number of respondents is presented in right-hand side graph of the Figure 3. Comparing this graph with right-hand side graph of the Figure 5, it can be observed that higher percentage of respondents reported higher annoyance due to construction noise.

[3] For details, refer to the European Directive (Directive 2002/49/EC 2002)
[4] SLM is denoted as Sound Level Meter throughout this document

**Table 2:** Number of Control Positions installed at different railway sites

| | Site A | Site B | Site C | Site E | Site F | Site H | Site I | Site J | Site K | Site L |
|---|---|---|---|---|---|---|---|---|---|---|
| No of respondents | 115 | 30 | 9 | 64 | 61 | 87 | 155 | 235 | 45 | 43 |
| Av. $L_{den}$ | 57.9 | 58 | 53.8 | 67.2 | 59.6 | 62.2 | 63.2 | 60.2 | 61 | 62.9 |
| Min $L_{den}$ | 40.4 | 49.7 | 51.3 | 58.6 | 54.4 | 56.9 | 57 | 53.1 | 49.6 | 57.4 |
| Max. $L_{den}$ | 61.2 | 61.5 | 56 | 73.9 | 63.1 | 68 | 68.6 | 66.9 | 70.4 | 67.4 |

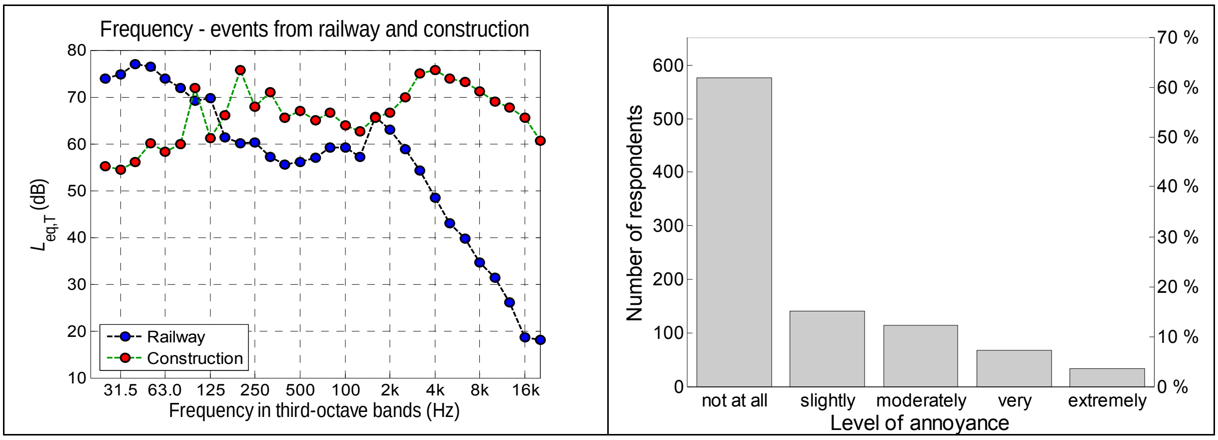


**Figure 3:** This figure presents, on left-hand side graph, the comparison between noise spectrum from railway and construction. The right-hand side graph presents number of respondents exposed to railway noise versus level of annoyance in 5-point semantic scale (DD ISO/TS 15666:2003).

The estimated cumulative probabilities of annoyed respondents as functions of $L_{den}$ are included in Figure 4. The left-hand side graph shows residents reported to be "annoyed" and "highly annoyed" (the categories 4 and 5 in 5-point semantic scale, DD ISO/TS 15666:2003). The right-hand side graph shows residents reported to be "highly annoyed".

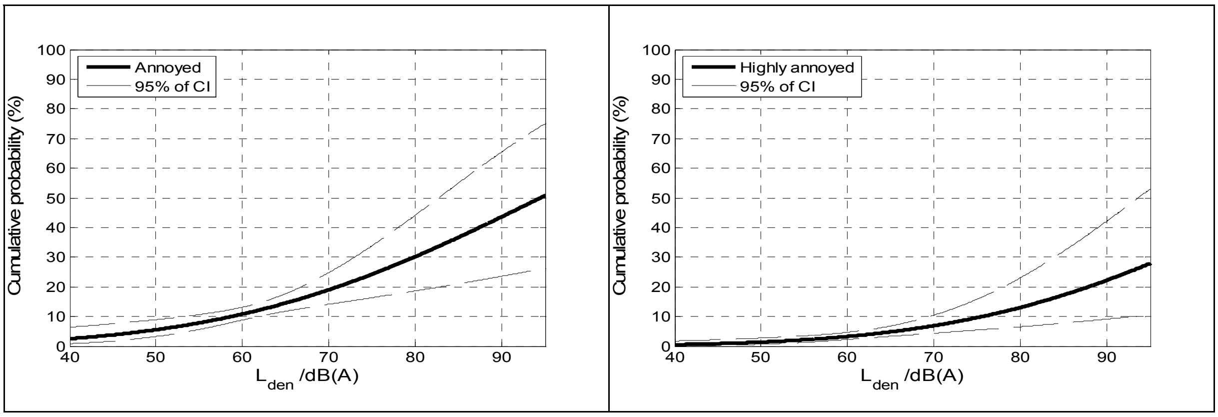


**Figure 4:** The exposure-response relationship between railway noise and annoyance measured in 5-point semantic scale (DD ISO/TS 15666:2003)

The results from estimation of the ordinal probit regression model, is shown in Table 3. The overall model and its coefficients were found to be significant.

**Table 3:** Results from ordinal probit model analysis due to noise from railway and annoyance level

| Variables | | Estimated thresholds | Std. Error | 95% CI | Signific. |
|---|---|---|---|---|---|
| Dependent var. (annoyance level) | "4" + "5" (5) | 3.3878 | 0.6091 | 2.1939 – 4.5818 | 0.00* |
| | "5" (5) | 3.9926 | 0.6137 | 2.7898 – 5.1954 | 0.00* |
| Ind. variable ($L_{den}$) | $L_{den}$ | -0.0359 | 0.0098 | -0.0552 – -0.0166 | 0.00** |

* $p<0.0001$, ** $p<0.0005$; for total model: $\chi$-test $p<0.0001$; N = 816.

## Construction noise exposure

This section provides the outline results from calculation of noise and the prediction of annoyance from construction work. The typical frequency content of a construction source is shown by left-hand side graph of the Figure 3. The overall noise level affecting the community is shown in Figure 5. Three different groups of bars correspond to three groups of community, as followed: (a) combined group of people from two sites, (b) separate community groups exposed to noise in Site B and (c) Site A.

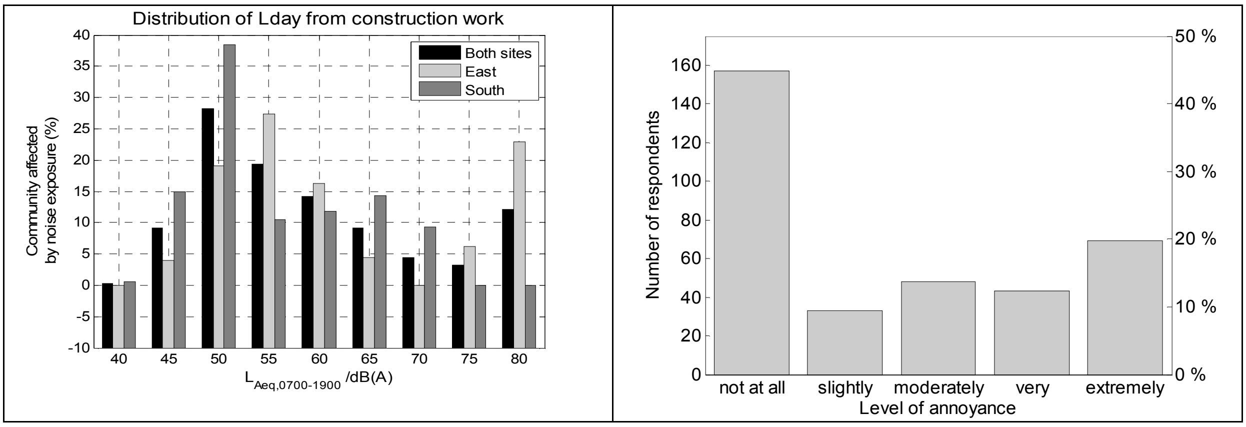


**Figure 5**: This figure presents 2 graphs, the percentage of residents exposed to noise levels from construction sites (an overall exposure, exposure from South and East) and number of respondents versus annoyance level in 5-point semantic scale (DD ISO/TS 15666:2003).

The largest number of respondents are subjected to 50 dBA considering combined sites. In Site A, the majority of respondents were affected by noise levels around 50 dBA. In Site B, on the other hand, two distinct groups are subjected to a noise level $L_{den}$ equal to 55 dBA and 80 dBA. The highest values of noise level was the result of a point of reception being in close vicinity to a source whereas the lowest value of the noise level was caused by a reduction due to obstacles and shielding.

Similarly to Figure 4, Figure 6 shows two graphs that contain the estimated cumulative probabilities of annoyed respondents as functions of $L_{day}$. The left-hand side graph shows residents reported to be "annoyed" and "highly annoyed" (the categories 4 and 5 in 5-point semantic scale, DD ISO/TS 15666:2003). The right-hand side graph shows residents reported to be "highly annoyed".

[5] In 5-point semantic scale (DD ISO/TS 15666:2003), the categories are named as followed: "0 - do not notice", "1 - not at all", "2 - slightly", "3 - moderately", "4 - very", "5 - extremely"

The results from estimation of the ordinal probit regression model are shown in Table 4. The overall model and its coefficients are highly significant.

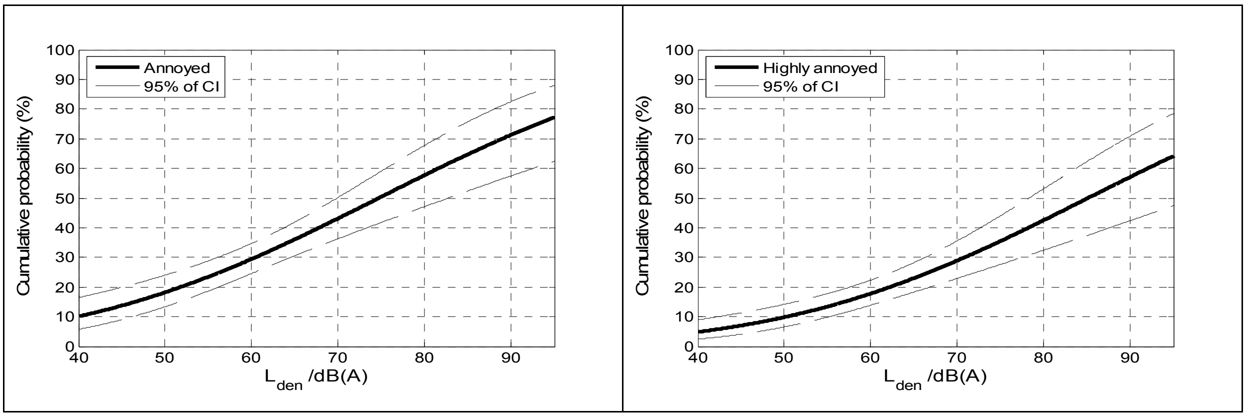


**Figure 6:** The exposure-response relationship between construction noise and annoyance measured in 5-point semantic scale (DD ISO/TS 15666:2003)

**Table 4:** Results from ordinal probit model analysis due to noise from construction and annoyance

| Variables | | $\beta_0$ and $\beta_1$ | Estimated thresholds | Std. Error | 95% CI | | Significance |
|---|---|---|---|---|---|---|---|
| Dependent var. (annoyance level), | $\beta_0$ | "4" + "5" $^{(5)}$ | 2.7455 | 0.3869 | 1.9872 | 3.5039 | 0.00* |
| | | "5" $^{(5)}$ | 3.1282 | 0.3928 | 2.3583 | 3.8982 | 0.00* |
| Ind. variable ($L_{den}$) | $\beta_1$ | | -0.0367 | 0.0098 | -0.0552 – | -0.0166 | 0.00* |

* p<0.0001; for total model: $\chi$-test p<0.0001; N = 324.

## UNCERTAINTIES ASSOCIATED WITH CALCULATION

Uncertainties were estimated based on the paper of Craven & Kerry (2001) and were followed by calculation also included in Technical Report 3 by Sica et al. (2011).

Uncertainties, related to railway noise, had to be estimated due to assumptions, which covered the number problems. Most of them are related to the number of vehicles that a train is comprised of, the number of trains during the daytime, evening and night time, the distance between the source and receiver that were estimated from maps, and speed of trains travelling through residential areas. The combined uncertainties were found to be 2 dBA, including 95% confidence interval.

Uncertainties in construction sites were caused by sources of much greater noise level and limited dynamic range of spectral content measurements. Due to different positions of sources, a ground reflection component did not always influence the final results. Additionally, larger uncertainties were set due to the limited dynamic range of the SLM when measuring the spectral content of loud sources (exceeding 80 dBA). Expanded uncertainty (95% confidence [k = 2]) was found to be 4.5 dBA.

## CONCLUSION

The main purpose of the survey presented here was to obtain exposure-response curves for vibration from railway and construction sources. However, participants were also asked about annoyance due to noise and the resulting data was sufficiently detailed to permit the derivation of exposure-response relationships for noise from the same sources which are presented here. These curves thus serve to complement the exposure response curves derived for vibration.

The curves indicate that, for the same exposure, expressed in terms of $L_{den}$, the annoyance due to construction noise is greater than that from railways. We can speculate that factors other than noise and vibration, such as dust and disruption to traffic etc. contribute to the higher annoyance from construction.

Details of the vibration survey which was carried out at the same time as the noise survey can be found in Technical Report 3 "*Calculation of vibration exposure*" (Sica et al. 2011).

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# Community reaction to railway vibration at different times of the day

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## INTRODUCTION

Nighttime and evening time noise have a greater impact on annoyance in residential areas than daytime noise of the same level. A number of studies showed different sensitivities with respect to noise exposure during the day, evening and night in particular for air traffic (Fields 1986a, b; Miedema et al. 2000; Schreckenberg & Meis 2006). $L_{den}$ was proven to be a good indicator for long term effects (notably annoyance). $L_{den}$ incorporates different weighting factors for noise in the evening and night for predicting annoyance (5 dB penalty for 19-23 h, and 10 dB penalty for 23-7 h). $L_{den}$ is one of the EU-indicators for environmental noise (EU Directive 2002/49/EC) and it is currently used to illustrate exposure-response relationships for transportation noise (Miedema & Oudshoorn 2001).

In the same way, the time of day at which vibration occurs might be a factor affecting the impact of vibration in the community. Evening and night penalties have to be investigated in order to derive a dose-response relationship for railway vibration. The current British standard BS 6472-1:2008 recommends using the Vibration Dose Value (VDV) as a vibration descriptor, which is a measure of the cumulative exposure to vibration during the measurement period and uses two frequency weighting curves for vertical and horizontal vibration, based on the human perception thresholds of vibration. VDV takes into account the number of events and their duration, but on the other hand there are no penalties determined in its calculation for different times of the day. The standard only recommends separate limit values for day and night times. Moreover, a few studies have suggested that vibration causes some rest and sleep disturbance (Arnberg et al. 1990; Klaeboe & Fyhri 1999; Öhrström et al. 2009; Ögren & Öhrström 2009) and annoyance reactions are more frequent during evening and nighttime (Öhrström 1997). However, publications tend to show both sleep disturbance and nighttime annoyance as a function of a 24-hour vibration measure.

In the present study the effects of vibration at different times of day as well as the weights for each time period are assessed performing different analyses on the survey and vibration data. In the first part the time-period annoyance ratings are related to time-period vibration levels and then the exposure-response relationships from each period are compared. The second part investigates responses to vibration using all available information about nighttime vibration levels. Finally the research findings are presented. The data used here were collected within the UK study "Human Response to Vibration in Residential Environments" by the University of Salford and funded by the Department for Environment, Food and Rural Affairs (Defra) UK.

## METHODS

### Study design and sample

The overall aim of the study "Human Response to Vibration in Residential Environments, UK" was to derive exposure-response relationships between vibration exposure and annoyance from railway, construction and internal sources. The data in this paper relate to response from railways only and were collected in the UK, more specifically in the North-West and the Midlands areas of England during 2009 and 2010.

The study sites were chosen to provide an overall representative and robust sample size, as well as to maximize the range of exposures to vibration and maximize the potential number of respondents. This was achieved by selecting sites within a range of distances from the railway, different railway traffic, and different kinds of properties. Mainly the sites were identified depending on the population density and distance from the vibration source. Properties within a distance of 100 meters to the railway were targeted to ensure a high enough vibration level perceptible for the respondents. Locations were also chosen to provide a representative socio-demographic sample of the UK's population.

Face-to-face questionnaires were used and the total number of completed questionnaires relating to railway vibration was 931 with associated high-quality vibration data being obtained internally in respondent's properties.

### Vibration exposure

The measurement of vibration was carried out using Guralp CMG-5TD accelerometers and the measurement protocol employed consisted of long term vibration monitoring at an external position (generally a garage or a shed) along with time synchronized short-term internal snapshot measurements. By determining the velocity-ratio between the control and internal measurements, an estimation of 24-hour internal vibration exposure was obtained (Woodcock et al. 2009; Peris et al. 2011).

For each respondent, vibration dose values ($VDV_b$ for vibration in the vertical direction and $VDV_d$ for vibration in the horizontal direction) in accordance with BS 6472-1:2008 were calculated over three different time periods defined as: daytime between 7:00 – 19:00 h, evening between 19:00 – 23:00 h, and night between 23:00 – 7:00 h.

### Questionnaire

Study respondents self-assessed their degree of annoyance in particular time periods due to railway vibration on a 5-point semantic scale, as recommended by the standard ISO/TS 15666:2003 (Condie et al. 2009). In the survey, annoyance during different time periods was assessed, from respondents who stated being somehow annoyed by vibration, and through the following question: "Thinking about the last 12 months or so, when indoors at home, how bothered, annoyed or disturbed you have been by feeling vibration or hearing or seeing things rattle, vibrate or shake caused by the railway between day (7 a.m. to 7 p.m.), evening (7 p.m. to 11 p.m.), night (11 p.m. to 7 a.m.), Would you say not at all, slightly, moderately, very or extremely?".

The annoyance response categories were converted onto a continuous annoyance scale from 0 to 100. This conversion is based on the assumption that a set of categories divides the range from 0 to 100 in equally spaced intervals. Exposure-response relationships are generally analyzed for the percentage of highly annoyed people (%HA), percentage of annoyed people (%A), and percentage of little annoyed people (%LA). According to ISO/TS 15666:2003, a person has been defined as being highly annoyed when he or she chooses "very" or "extremely" in the 5-point semantic scale. Likewise, categories including "moderately" and above correspond to annoyed whereas categories including "slightly" and above correspond to little annoyed.

The social survey questionnaire also asked respondents to state if their sleep was ever disturbed by vibration caused by railway activity. The response to this question was either “Yes” or “No”.

### Statistical analyses

To examine the exposure-response relationships between vibration level and annoyance at different times of day, ordinal logit models (Klæboe et al. 2003) were used to generate parameter estimates for the annoyance thresholds (not at all, slightly, moderately, very and extremely). Equation (1) was used to obtain the estimated exposure-response relationships from the estimated parameters. The equation indicates the probability of obtaining a vibration annoyance response equal to or higher than $j$ :

$$P(Y \geq j \mid \mathbf{X}_i = \mathbf{x}_i) = 1 - ((e^{\hat{\tau}_j - \hat{\beta}' \mathbf{x}_i}) / (1 + e^{\hat{\tau}_j - \hat{\beta}' \mathbf{x}_i}))\, j \in [1, ..., J-1] \quad (1)$$

where $\hat{\tau}_j$ indicates the $j$th estimated threshold, and $\hat{\beta}$ is the estimated parameter for the exposure value. There are $J$ annoyance categories. $\mathbf{X}_i$ is a vector of exposure for an individual $i$.

Binary logistic regression analysis was used to examine the relationship between sleep disturbance (Yes/No question) and vibration exposure.

## RESULTS

### Vibration annoyance at different times of the day

In this section the time-period responses are related to the time-period vibration levels. Table 1 shows the results from the ordinal logit model parameter estimations. These results are used to calculate the estimated exposure-response relationship in Equation (1). For example, to calculate the proportion of respondents who are estimated to be annoyed by a $VDV_b$ of 0.01 $m/s^{1.75}$ during the day, the estimated parameter values (Table 1) of the relevant threshold and location (exposure) parameter were inserted into the expression as follows:

$$P(Y \geq j \mid \mathbf{X}_i = \log_{10}(0.01)) = 1 - ((e^{2.377 - \log_{10}(0.01) \times 0.636}) / (1 + e^{2.377 - \log_{10}(0.01) \times 0.636})) \approx 0.02$$

The result shows that about 2 % of the respondents are highly annoyed at a $VDV_{b,7:00\text{-}19:00}$ of 0.01 $m/s^{1.75}$ exposure level. Figure 1 shows the exposure-response relationship for day, evening and night times. The curves indicate the percentage of residents expected to be highly annoyed by given vibration exposure levels from the railway. The grey bands indicate the 95 % confidence intervals of the relationships between exposure and annoyance at different times of day. The figure indicates that, for example, with the same vibration exposure ($VDV_b$) of 0.05 $m/s^{1.75}$, 4 % are highly annoyed during the day, 7 % during the evening and 15 % during the night. This means that many people are more annoyed at night compared to vibration during the day and evening at the same vibration levels.

**Table 1:** Parameter estimates for railway traffic vibration annoyance during the day, evening and night using ordinal logit model

| Parameter Estimates | Estimates | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Day | 95 % CI | | Evening | 95 % CI | | Night | 95 % CI | |
| | | Lower | Upper | | Lower | Upper | | Lower | Upper |
| Threshold ( $\hat{\tau}$ ) | | | | | | | | | |
| Highly annoying | 2.377 | 1.517 | 3.237 | 1.491 | 0.700 | 2.282 | 0.505 | -0.198 | 1.208 |
| Location ( $\hat{\beta}$ ) | | | | | | | | | |
| $Log_{10}VDV_b$ | 0.636 | 0.139 | 3.237 | 0.820 | 0.364 | 1.276 | 0.931 | 0.512 | 1.350 |

All results are statistically significant ($p$<0.05); N=755; Cox & Snell $R^2_{day}$=0.008; Cox & Snell $R^2_{evening}$=0.016; Cox & Snell $R^2_{night}$=0.026.

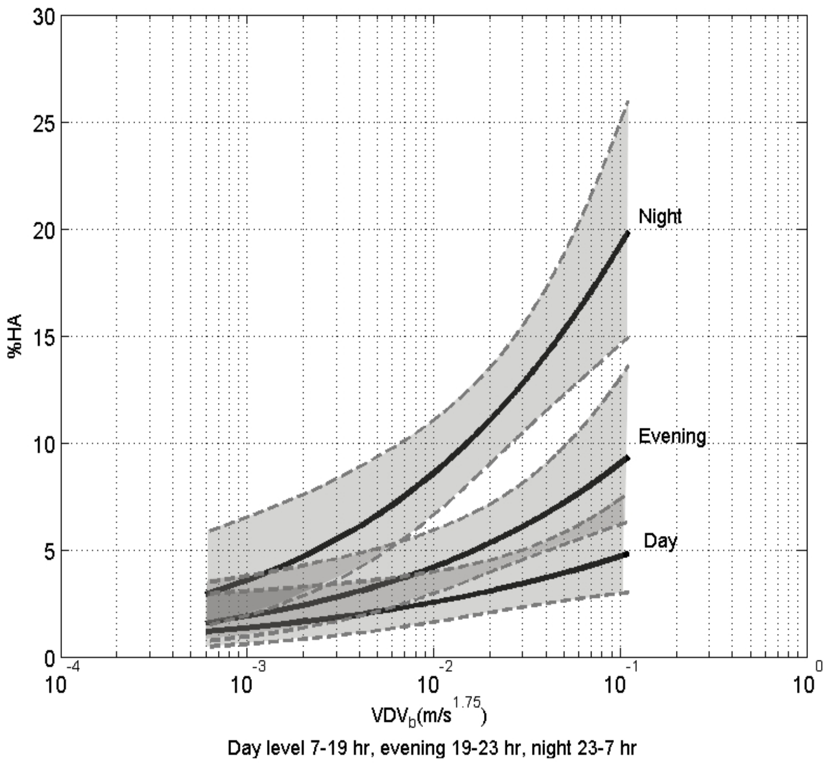


**Figure 1:** Comparison of the proportion of people reporting high annoyance (%HA) during the day, evening and night due to railway vibration (vertical vibration $VDV_b$). Curves are shown in their 95 % confidence intervals.

Figure 2 shows the distance between the annoyance responses for the day, evening and nighttime. The distance between the annoyance responses ($W_e$, $W_n$) is based on the distance between the curve for the daytime and the curve for each of the other time periods. These time period differences can be converted into time-of-day weights. For example, a $VDV_b$ of 0.1 $m/s^{1.75}$ in the day shows the same proportion of highly annoyed respondents as a $VDV_b$ of 0.015 $m/s^{1.75}$ during the evening. Thus, a penalty should be applied to eveningtime exposures when combining the vibration exposures in different periods into a single 24-hour descriptor. Likewise, a $VDV_b$ of

0.1 m/s$^{1.75}$ in the daytime shows the same proportion of highly annoyed respondents as a $VDV_b$ of only 0.002 m/s$^{1.75}$ during the night. On the basis of these results a factor of 6.7 ($W_e$) and a factor of 50 ($W_n$) for evening and nighttime exposures respectively should be applied when calculating an overall VDV descriptor as indicated in Equation 2.

$$((W_e \times 0.015)^4)^{0.25} = 0.1 \quad W_e = 6.7$$

$$((W_n \times 0.002)^4)^{0.25} = 0.1 \quad W_n = 50$$

$$VDV_{b,den} = \left[ VDV_{b,7:00\text{-}19:00}{}^4 + (W_e \times VDV_{b,19:00\text{-}23:00})^4 + (W_n \times VDV_{b,23:00\text{-}7:00})^4 \right]^{0.25} \qquad (2)$$

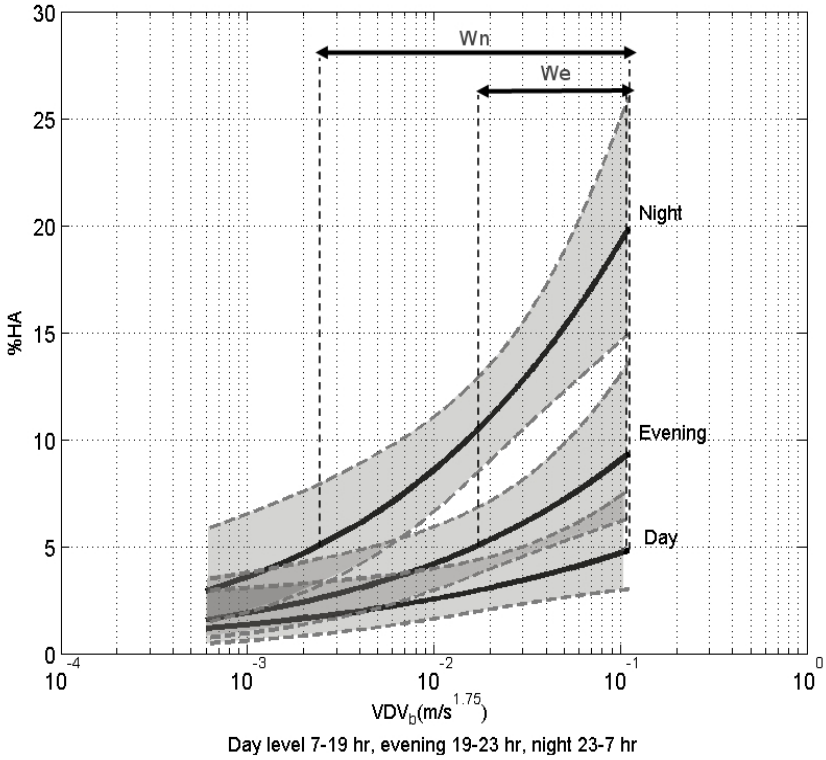


**Figure 2:** Comparison of the proportion of people reporting high annoyance (%HA) during the day, evening and night due to railway vibration (vertical vibration $VDV_b$). Curves are shown in their 95 % confidence intervals.

## Night annoyance and sleep disturbance

Nighttime annoyance and sleep disturbance caused by vibration can be assumed to be somehow related as reducing sleep disturbance can be the basis for reducing nighttime annoyance. The vertical direction of vibration is dominant on the ground floor and the horizontal direction on higher floors (Madshus et al. 1996). Sleep disturbance and night annoyance caused by railway vibration can be assumed to happen where the bedroom of the respondent is located, which for typical British houses is on the first floor. From Table 2 it can be seen that the nighttime relationship is highly improved using the horizontal vibration exposure $VDV_d$.

This section intends to investigate responses to vibration using all available information about nighttime vibration levels. Two types of information about nighttime responses are presented.

Figure 3 relates the extent of nighttime annoyance to nighttime vibration levels $VDV_{d,23:00\text{-}7:00}$ (horizontal direction). The cumulative exposure-response curves are derived using the ordinal logit model described in the previous section. The lower curve indicates the percentage of residents expected to be highly annoyed during the nighttime by given exposure levels from the railway traffic. The upper curves indicate the cumulative percentage of respondents who are at least annoyed and at least little annoyed during the nighttime.

**Table 2:** Parameter estimates for nighttime railway vibration annoyance using ordinal logit model

| Parameter estimates | Estimates | | | |
|---|---|---|---|---|
| | Estimates | SE | 95% CI | |
| | | | Lower | Upper |
| Threshold ( $\hat{\tau}$ ) | | | | |
| Little Annoyed | -2.238 | 0.637 | -3.487 | -0.989 |
| Annoyed | -1.844 | 0.636 | -3.090 | -0.598 |
| Highly annoyed | -1.145 | 0.636 | -2.391 | 0.101 |
| Location ( $\hat{\beta}$ ) | | | | |
| $Log_{10}VDV_{d,\ 23:00\text{-}7:00}$ | 1.213 | 0.243 | 0.736 | 1.691 |

All results are statistically significant ($p$<0.05); N=755; Cox & Snell $R^2$=0.036.

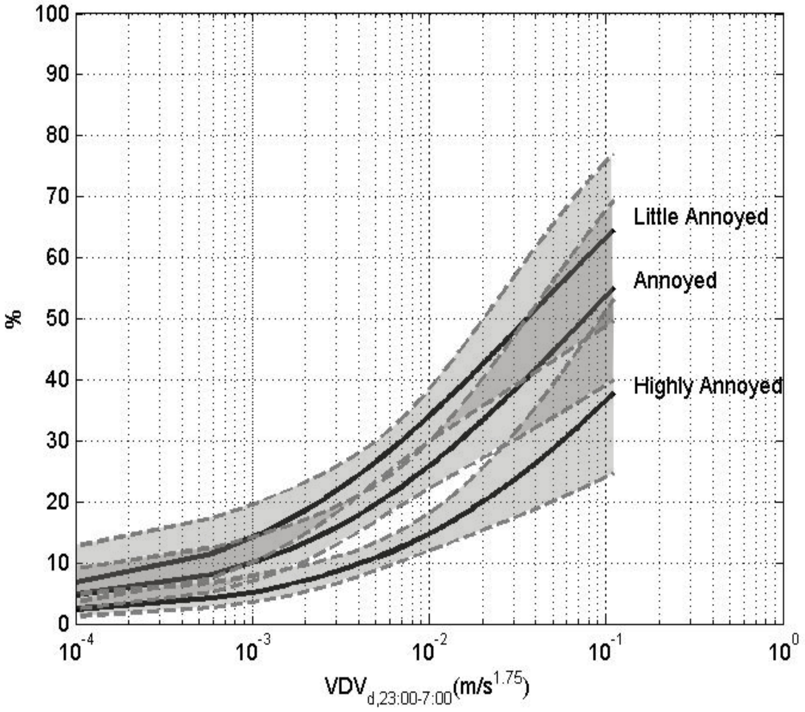


**Figure 3:** Cumulative exposure-response curve for $VDV_{d,23:00\text{-}7:00}$ and the proportion of respondents who express different degrees of nighttime vibration annoyance due to railway traffic

Figure 4 shows the proportion of respondents reporting sleep disturbance for a given magnitude of vibration exposure ($VDV_{d,23:00-7:00}$) and Table 3 shows the results from the logistic regression parameter estimates.

**Table 3:** Logistic regression results showing the relationship between sleeping disturbance and vibration exposure $VDV_{d,23:00-7:00}$

| Parameter estimates | Estimates | | | |
|---|---|---|---|---|
| | Estimate | SE | 95 % CI | |
| | | | Lower | Upper |
| Intercept | -2.547 | 0.686 | -3.892 | -1.202 |
| $Log_{10}VDV_{d,\ 23:00-7:00}$ | 1.394 | 0.264 | 0.878 | 1.911 |

All results are statistically significant ($p$<0.05); N=755; Cox & Snell $R^2$=0.042.

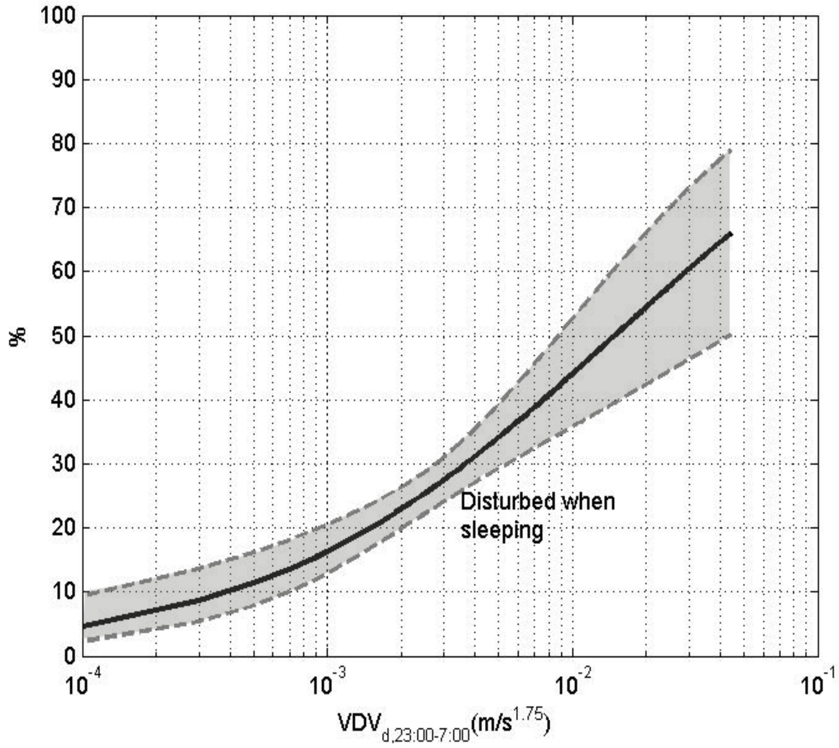


**Figure 4:** Proportion of respondents reporting being sleep disturbed by railway vibration for a given exposure $VDV_{d,23:00-7:00}$

## CONCLUSIONS

People's reactions due to railway vibration at different times of the day have been investigated through analyses of time-period vibration levels and time-period annoyance. These analyses showed that different times of the day have a different impact on vibration annoyance, thus, separate time of day weights should be applied when considering a dose-response relationship from railway vibration in residential environments. For an optimal assessment and reduction of people annoyed by railway vibration these results should to be taken into account by policy makers, environmental health practitioners and planners.

The exposure-response relationships suggest that annoyance is greater in residential areas during evening and nighttime periods. It was found that a metric based on weights for periods 19:00-23:00 and 23:00-7:00 would be the most appropriate for predicting railway vibration annoyance.

Nighttime disturbances were better correlated with horizontal vibration exposure ($VDV_d$). This result highlights the importance of horizontal vibration measurements in studies and assessments involving sleep disturbance or night annoyance.

## ACKNOWLEDGMENTS

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# Socio-acoustic survey and soundscape analysis in urban parks in Rome

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## INTRODUCTION

The Directive 2002/49/EC of the European Parliament and of the Council relating to the assessment and management of environmental noise and the Italian decree of transposition D.Lgs. 194/2005 introduce the concept of "quiet areas", either in agglomeration or in open country. Unfortunately, metrological criteria to identify such areas have not been defined yet, mainly due to the lack of knowledge of the effect of noise on their perceived soundscape quality (Nilsson 2007).

Several studies carried out over the last decade have shown that it's more realistic and useful an approach aimed to analyze the perception of the acoustic quality of the environment, rather than using noise indicators describing the sound environment only, i.e. the equivalent sound pressure level ($L_{Aeq}$) or the day-evening-night level ($L_{den}$) (Schulte-Fortkamp & Dubois 2006; Brown 2006; Kang 2007).

The importance of "quiet areas", or even better "areas of high acoustic quality" (Brown 2006), is widely recognized as they provide, at least temporarily, opportunities for relaxation and stress recovery from noise pollution to which the population is exposed in the everyday life. This health-promoting function should be preserved and improved, especially for the urban parks, as they can be easily accessed by the users but, meanwhile, are often surrounded by noisy areas due to the sound emission of road traffic, industries and other sources.

This paper describes a socio-acoustic survey carried out in three urban parks in Rome aimed to investigate the users' perception of the acoustic quality in the parks and its relationship with some acoustic parameters. The study is the first one in the urban green areas in Rome having structure and methodology comparable with the previous surveys carried out in urban parks in Naples and Milan (Brambilla et al. 2006). A preliminary survey on the web was performed to provide information useful to design the questionnaire to be used in the field survey and to identify the areas to be investigated. The in situ surveys were carried out taking binaural recordings of the sound environment and simultaneous interviews to people in the park. The results of the surveys have been related to the acoustic data determined from the recordings.

## SELECTION OF THE URBAN PARKS

A preliminary survey was performed to identify the most frequented urban parks in Rome and to assess other aspects of these areas. In order to reach quickly an adequate number of participants, the survey was carried out on the web by a questionnaire containing 15 questions and proposed for filling in by e-mail to people living in the municipality of Rome. The questionnaire was available on the web for 15 days in May 2010 and 121 persons answered to it.

The questions dealt with the most frequented green areas, the most pleasant and unpleasant ones, the reason for going to the park, the degree of satisfaction of the sound environment and of the area considering all its aspects.

Based on the outcomes of this poll, the urban parks of Villa Pamphili, Villa Borghese and Parco della Caffarella were selected for the field survey. Figure 1 reports the percentages of respondents for the 5 degrees of satisfaction of the sound environment and of the area considering all its aspects. The dashed line represents equal percentage of respondents satisfied equally by the sound environment and all the aspects of the area.

In the selected three parks preliminary surveys were carried out to identify the zones most frequented by people and of different use (children's play areas, paths for sport activities, etc.).

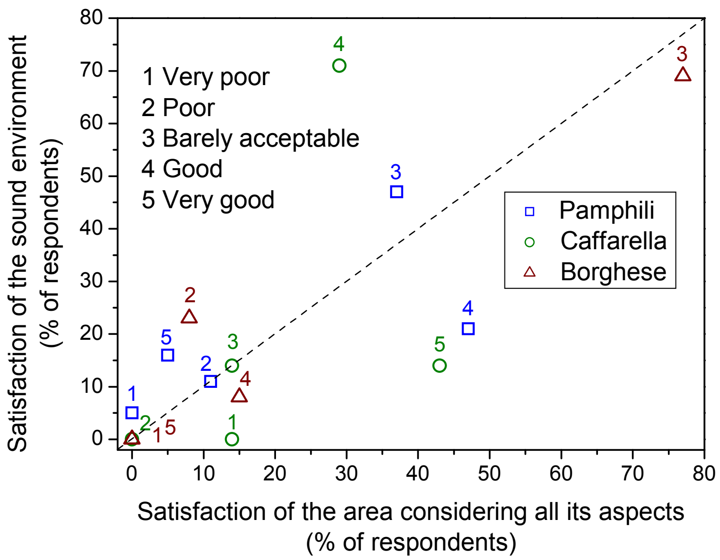


**Figure 1:** Degree of satisfaction of the three green areas

## Features of the urban parks

The three urban parks chosen for the study are situated inside the agglomeration of Rome and show different features, i.e. the presence of historical, monumental and natural elements.

Villa Borghese (about 80 hectares) is surely one of the most famous parks of Rome and Italy. It is enriched by the presence of historical and architectural buildings and, therefore, it is frequented by many tourists and often used for exhibitions and concerts. The sound environment is characterized by anthropic sounds and traffic noise from the vehicles passing on the streets surrounding and crossing the park.

Villa Pamphili (180 hectares) is one of the best preserved parks: the main change from the past is a busy road that divides the area into two parts. There are natural zones, not easily accessible and therefore less visited, while the areas close to the entrances of the park are the most used. There are a bar, two playgrounds, a location for sports facilities, a large area for dogs.

Covering over 190 hectares, Parco della Caffarella owes its cultural and historical feature to its location, close to two main ancient roads: Via Appia Antica and Via Latina. Its structure differs from the other parks and it shows mainly natural features. It is a neighborhood park, usually frequented by the residents in the area, mainly for jogging, cycling, and there are play areas for kids. Natural sounds prevail even if aircraft noise is perceived due to the fly-overs from/to Ciampino airport.

## IN SITU SURVEYS

The sound environment in each of the three parks was recorded binaurally in fixed positions distributed in the areas, rather than during soundwalks. The recordings were made for periods of about 5 minutes, using binaural headphones worn by the operator and connected to a digital audio recorder. During the recordings sound sources and noticeable sound events were pointed out by the observer.

Face to face interviews were carried out simultaneously with the sound recordings by means of a questionnaire adapted from that used in the preliminary on-line poll. The questions dealt with details of the presence in the park (frequency, days, hours and average time of attendance), means to reach the area (car, public transport, bicycle, etc), the main reason for attending the park, the degree of satisfaction of the area as a whole and of its sound environment. In addition, the assessment of 20 aspects of the area, expressed by a score on a scale from 1 (very poor) to 10 (very good), was collected together with the interviewee's personal information (age, educational level, occupation, etc.) and the indication of her/his most frequented areas or paths in the park.

Table 1 reports the number of binaural recordings and interviews carried out in the three parks.

**Table 1:** Binaural recordings and interviews carried out in the three parks

| Park | N. of recordings | N. of interviews |
|---|---|---|
| Villa Borghese | 30 | 88 |
| Villa Pamphili | 31 | 79 |
| Parco Caffarella | 24 | 61 |
| Total | 85 | 228 |

## RESULTS AND DISCUSSION

The analysis of the 228 interviews shows that sounds from nature are the most perceived and desired, as shown in the frequency distribution plot in Figure 2.

Considering all the opinions expressed on the 20 aspects of the three urban parks, the presence of trees (average score 8.2) and tranquility (average score 8.0) were rated better than natural sounds (average score 7.7) and silence (average score 7.6), as shown in Figure 3.

Pooling the respondents rating "good" and "very good" the sound environment in the three parks, a 74 % value was obtained, a bit lower than the threshold of 80 % established by the Swedish Environmental Protection Agency (2005) to identify a "quiet area". Figure 4 shows that 27 % of respondents rated the quality of the area considering all its aspects better than its sound environment and 30 % reacted contrariwise.

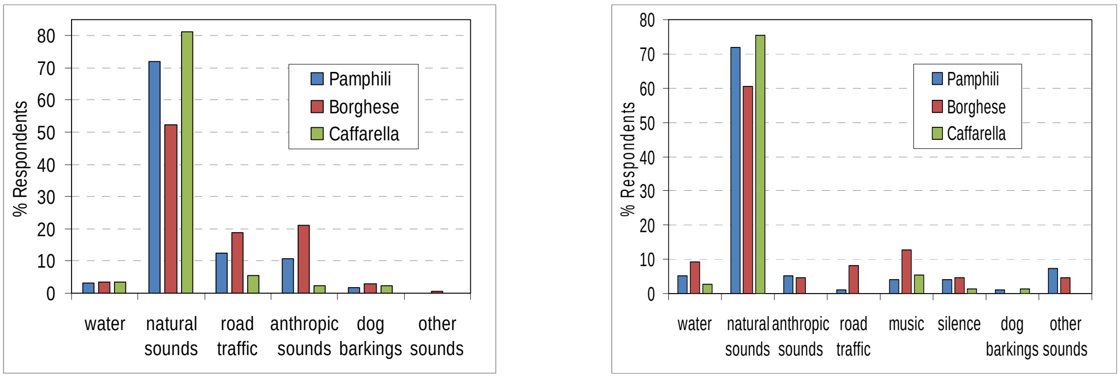


**Figure 2:** Sounds perceived (left) and desired (right) in the three parks

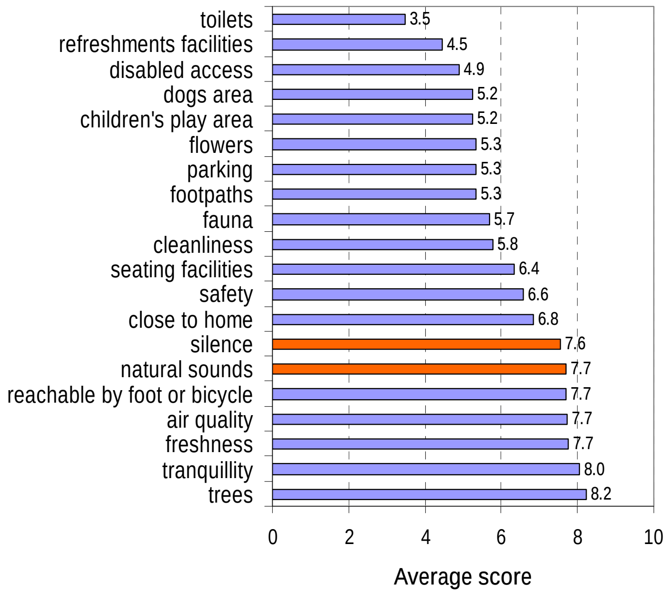


**Figure 3:** Rating of the various aspects of the parks (from 1=very poor to 10=very good)

It is known that personal expectation and experience form a contributory factor in the perception of soundscapes (Bruce et al. 2009) and to evaluate this aspect the responses on the sounds considered desirable to be heard in the park have been compared with those on the sounds actually perceived in the park. Figure 5 confirms once more that natural sounds are often perceived and desired, whereas traffic noise and voices are more frequently perceived than desired.

The binaural recordings of the sound environment have been analyzed to determine several noise parameters, i.e. $L_{Aeq}$, $L_{An}$, the unweighted spectrum centre of gravity G (Grey & Gordon 1978), observed as a good measure for the degree of pollution of the soundscape with traffic noise (De Coensel & Botteldooren 2006), the number of sound events exceeding $L_{A50}$ by 3 dBA and $L_{A95}$ by 10 dBA, as well as psychoacoustic descriptors more related to the sound perception (loudness, sharpness, roughness and fluctuation strength). Before such analysis, unusual sound events that might affect the measures have been eliminated in the calculation of sound descriptors.

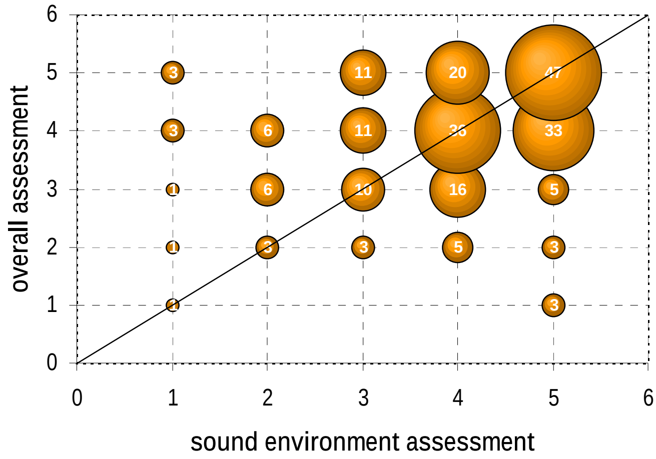


**Figure 4:** Overall assessment of the area vs. its sound environment for the three parks

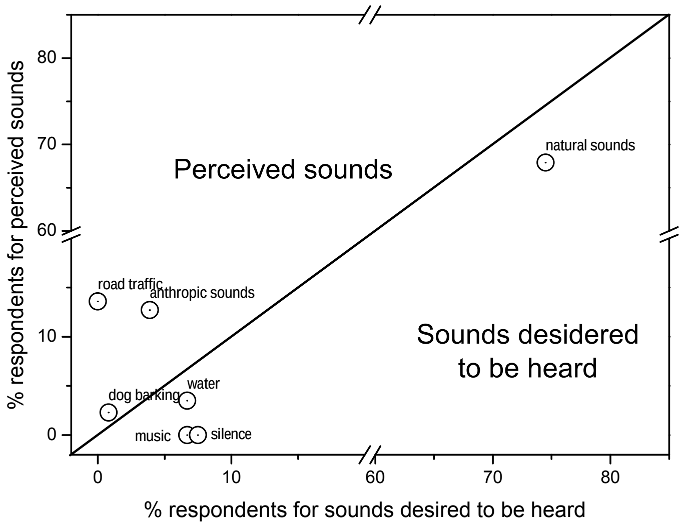


**Figure 5:** Comparison of sounds perceived and desired to be heard in the three parks

The distribution of the $L_{Aeq}$ values in the three parks is reported in the box plot in Figure 6. The white triangle is the median value and the red line at 50 dBA is the noise limit for day-time (06-22 h) established by the Italian legislation for the most sensitive areas of acoustic zoning, parks included. The average values observed in Villa Borghese and Villa Pamphili exceed the limit by 5-6 dBA. Despite this, approximately 70 % of respondents in both areas have expressed a positive rating on the sound environment. A better situation was observed in Parco della Caffarella where the average value of $L_{Aeq}$ is about 50 dBA, and this is confirmed by the higher satisfaction of users (87 %) of the sound environment. The smallest variability is observed in the data taken in Villa Borghese (interquartile 3.4 dBA), whereas larger (interquartile from 6.6 to 7.6) is the variability obtained for Parco della Caffarella and Villa Pamphili respectively. These differences in the $L_{Aeq}$ variability are likely due to the different type of sound sources in the three parks: in Villa Borghese anthropogenic sounds are predominant, whereas natural sounds prevail in Parco della Caffarella and Villa Pamphili shows a mixture of both sound sources.

Figure 7 shows the $L_{A50}$ values plotted versus the unweighted spectrum centre of gravity (lg G). Three areas can be identified, namely area 1 for $L_{A50}$<50 dB where 75 % of sites monitored in Parco della Caffarella are included, area 2 identified by $L_{A50}$>50 dB and lg G>2.1 containing 61 % of sites monitored in Villa Pamphili and area 3 delimited by $L_{A50}$>50 dB and lg G<2.1 where 77 % of sites monitored in Villa Borghese are included.

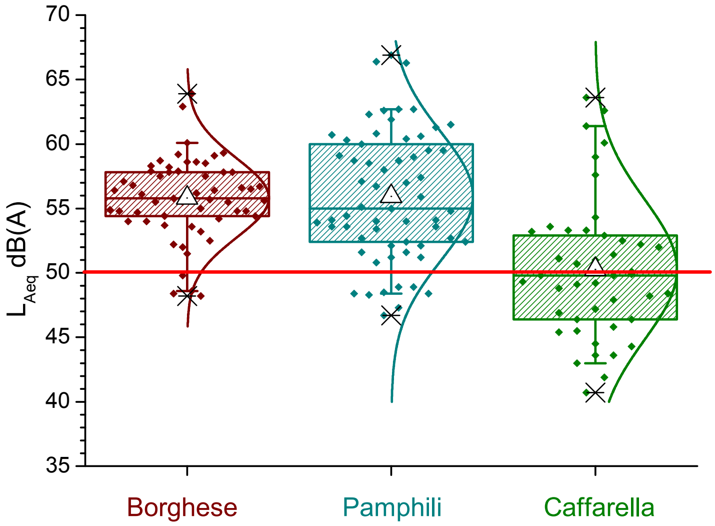


**Figure 6:** Distribution of the $L_{Aeq}$ values in the three parks

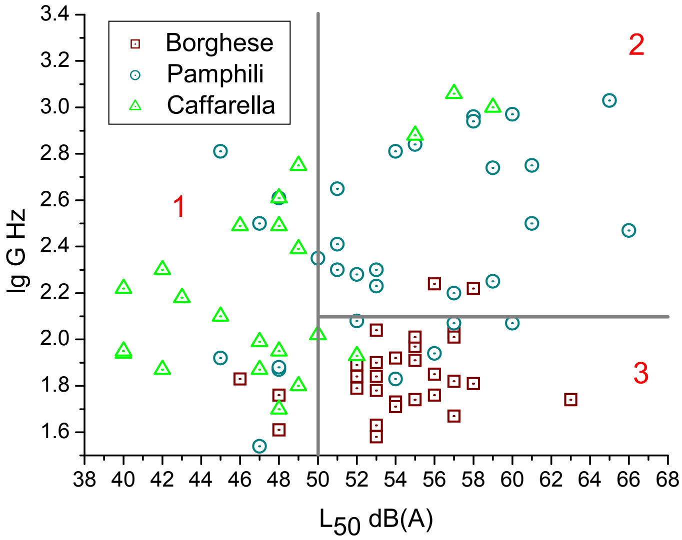


**Figure 7:** Values of $L_{A50}$ plotted versus the unweighted spectrum centre of gravity (lg G)

A preliminary attempt to summarize the data and to show them in order to be easily understood is given in Figure 8, reporting the aerial view of Villa Borghese together with the acoustic data given in the legend. In particular the box, placed at the position where the audio recording was taken, is red when $L_{Aeq}$ > 51 dBA, yellow for $L_{Aeq}$ between 49 and 51 dBA and green for $L_{Aeq}$ < 49 dBA.

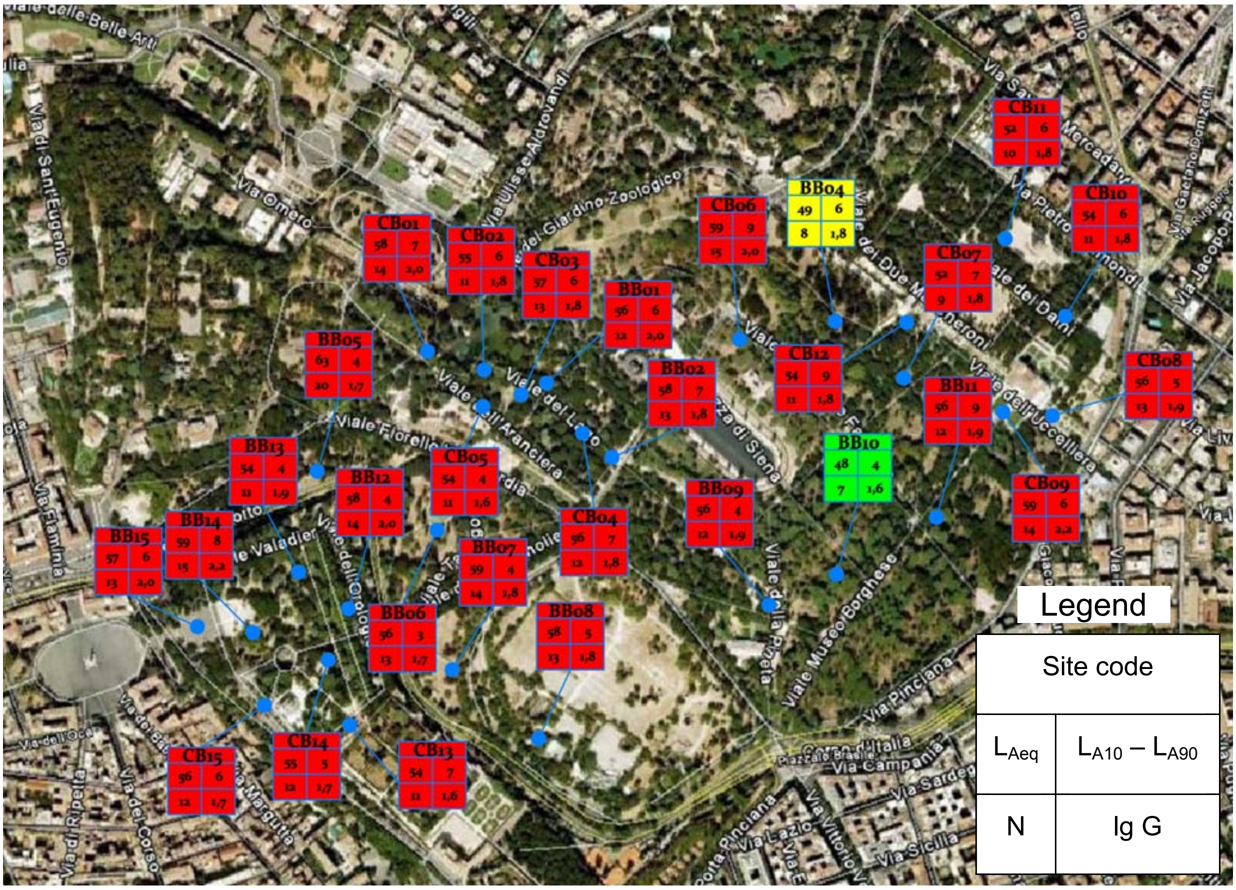


**Figure 8:** Aerial view of Villa Borghese with the main acoustic data

CONCLUSIONS

The analysis of the data collected in the field survey, involving 228 users of the three urban parks, shows that the sound environment is perceived as good (34 %) and very good (40 %). However, the three areas should not be considered quiet as in most of the sites the value $L_{Aeq}$= 50 dBA is exceeded (Nilsson & Berglund 2006). This value is also the noise limit established by the acoustic zone plan for sensitive areas and, therefore, noise mitigation actions should be undertaken, at least for Villa Borghese and Villa Pamphili. On the other hand, as said before, users seem to appreciate both the sound environment and the general conditions of the park.

This discrepancy clearly shows that the classical approach based exclusively on the use of the A-weighted equivalent sound pressure level is not sufficient to describe the quality of a sound environment, but it is necessary to consider other psychoacoustic parameters (loudness, etc.) and descriptors in the time-domain (percentile levels) and frequency (center of gravity of the spectrum). Moreover, the noise limits issued by the legislation so far are aimed to reduce the harmful effects of noise on health and, likely, would not be suitable for areas fulfilling a recovery and health-promoting function as the urban park should accomplish. In such areas the importance of subjective aspects, such as expectation and motivation, are crucial and they should be taken into account for their preservation and improvement.

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# Social survey about noise perception on Santos Dumont Airport neighbourhoods in Rio de Janeiro, Brazil – data collection and analysis methods

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## ABSTRACT

This work is concerned with the use of social survey about noise affected communities' perception as a parameter to improve airport noise environmental impact studies. Among July 2009 and December 2009 this author began this research applying a noise annoyance social research on Santos Dumont Airport neighborhoods'. Interviews were conducted in about 70 different addresses distributed on five distinct districts as a purposeful sample of residents indicated and priority contacted through residents associations. The interviews were conducted by this first author coordinating undergraduate students trained throughout 40 hours lessons course for developing field research skills. The scope of the questionnaire carefully elaborated to be applied during interviews and the data collecting and tabulation methods are presented in this work. This work yet in course aims contribute to better understand community response to airport noise considering the residents profiles and their perception about many other types of noise investigated throughout this survey. The survey plan is according to ISO15666 (2003) and its data analysis and tabulation are performed using surveys and statistics specialized software. The next steps involve applying new small questionnaire to check out changes on interviewed individuals' perceptions from 2009 to 2011 and also continuing tabulation data and performing sound measures in field.

## INTRODUCTION

Numerous social surveys have been conducted to assess the magnitude of noise`s problem since it began to be recognized as a serious environmental pollutant. Social surveys on annoyance due to airport noise are especially hard to be employed because the specificity of its noise source types. Beyond this there are the difficulties in analyze regions close to large urban centers where numerous other significant noise sources compose the acoustical scenario such as ground and water vehicles´ traffic, industrial areas, park alarms, etc. So airport noise measurements´ planning is very complex due to these other noise sources´ contribution that should be properly considered in final results (Vallet et al. 1998). In the case of applying social survey about airport noise`s annoyance the data collection considering residents` perceptions in their own sonorous environment would be more complex. On the other hand simulations performed throughout prediction´s models for airport noise such as the INM - Integrated Noise Model - are insufficient only themselves to establish a noise annoyance understanding and also their results are rarely compared with noise measurement´s data and almost never compared with data collected in noise annoyance social surveys (Nogueira & Mansur 2010).

Passing more than 30 years from the early well-known work published by Schultz in 1978 who established scales about noise annoyance throughout social surveys analysis even more recent studies on this subject are still inconclusive. Most of the information about communities' noise annoyance sensitivity is derived from generic health studies which include people affected by airport noise. The arguments about negative effects of airport noise on communities are still evaluated as unconvincing to support effective measures to mitigate the problem.

The metrics used in different countries to objectively evaluate the airport noise and the scales for subjective evaluation of noise annoyance both vary significantly. The complaints related to airport noise depend on qualitative factors such as education, culture, individual sensitivity and preferences, etc. Any way the objective factors such as frequencies of flight, flight schedule, distance between receptor location and the trajectories of flights, noise characteristics of the aircrafts, frequencies spectrum involved, among others items should be considered to adequately understand the annoyance due to aircraft`s noise levels.

Although today there is already a consensus on stimulating the DNL metric use to evaluate airport noise` levels which would facilitate the standardization of social acoustic surveys there is still a hot debate on values considered as levels´ limits which vary widely from country to country in up to 10 dBA for residential areas. In Brazil as well as in other countries laws on noise pollution use mostly based $L_{Aeq}$ metrics. In both cases using DNL or $L_{Aeq}$ metrics all the environmental impact studies generally do not consider the effect of the aircraft fly over as discrete event that is missing to be better studied as evaluating parameter. The isolated event of the aircraft passage can result in much higher immission levels at the receptor position than those average levels permitted by law.

DNL (Day Night Level) as a common measure of noise exposure is defined as bellow,

$$DNL = 10\log\left[\frac{1}{24\left(15\times 10^{\frac{DL}{10}}\right]} + 9\times 10^{\frac{(NL+10)}{10}}\right) \qquad [1]$$

Being $DL$ and $NL$ the average levels of noise during the daytime (07:00 to 10:00 p.m.) and night (10:00 p.m. to 7:00) respectively (SCHULTZ 1978).

$LAeq$ can be computed by following expression,

$$LAeq = 10\log\frac{1}{n}\sum_{i=l}^{n}10^{\frac{Li}{10}} \qquad [2]$$

being $Li$ the sound pressure level in dBA in fast response at 5 seconds during the noise measurement period and $n$ the total number of readings (ABNT 2000).

Generally in Brazil the regulations adopt the $L_{Aeq}$ as metric to establish the environmental noise levels as background noise to be compared with assessment criteria` levels (ABNT 2000). Moreover noise annoyance` evaluation is not well defined or not even used as parameter in sonorous environmental impact assessment studies. About airport noise impact evaluation studies are used the Noise Zoning Plans established in accordance with Ordinance 1141 GM5 (Brazilian Government Aeronautical Ministry 1987) and later laws to identify permitted land uses in the noise contours areas bounded by levels established in reference to DNL metric. The airport noise environmental impact studies performed in Brazil until now do not include the use of noise annoyance social surveys as a method to assess affected communities` noise perception nether use annoyance evaluation as parameter in environmental studies. The judgment about noise annoyance has been undertaken only on noise levels simulations and noise measurements carried out in accordance to the viewpoint`s consultant who carries out the noise impact study contracted and paid by the polluter as determine the federal laws in Brazil (Nogueira & Mansur 2010).

The present work still in process is looking for understanding adequately the annoyance due to airport noise in the way to contribute for community noise`s perception inclusion as parameter to enrich new acoustical environmental studies on airports. The case study is the Santos Dumont Airport and its neighborhoods that concern to the limits about five mostly residential districts in Rio de Janeiro city called Botafogo, Flamengo, Laranjeiras, Santa Teresa and Urca.

## METHODS

The first stage of this work presented last year at ICA2010 in Sydney (Nogueira & Mansur 2010) and shortly resumed below consisted synthetically in planning and performing interviews to residents from the five districts mentioned above. The interviews were applied to informants in 70 different addresses as a purposeful sample of inhabitants early identified by residents` associations as highly annoyed due to the airport noise. The second stage of this work just in progress include applying a new questionnaire to the same group of early interviewed residents aiming compare the noise community perception in 2009 to the community response in 2011.

### Social survey employed in 2009

The social survey performed in 2009 had the following activities about planning and applying the research.

1. Contact with residents associations to identify the noise annoyed residents aiming composition of purposive sample;
2. Participation on meetings with each district association interested in research to expose the social survey methods and goals creating confidence between researcher and residents;
3. Contacts were made carefully and repeatedly during a long period to conquest resident’s confidence as there is a wide concern about security risks in establishing household contacts especially in these case study areas;
4. Planning and executing of 40 hours course for under-graduate students to prepare them in developing field research skills to apply the questionnaires in households following known techniques for social surveys (IBGE 2004). In that time the questionnaire model was improved as it had been designed before;
5. Performing a household interviews campaign starting at July, 2009;

6. 70 questionnaires were completed by one informant per household reaching almost 200 people affected considering informers` co-inhabitants before December, 2009;
7. Some pilot measurements have been made since 2009 but not published until now because the procedures are still in test;
8. Research about alternatives to tabulate collected data throughout statistic software with lexical analysis plug-ins was made during 2010. Among two ones named CSPRO (US Census Bureau 2007) and SPHINX (2007) the last one was chose after many tests trying to reach satisfactory relating among the objective and subjective collected data;
9. Since October, 2010 it has been studied the software SPHINX in developing statistic tabulations and approaching collected data to adequately understand the social survey employed in 2009.

The questionnaire applied in 2009 was carefully developed and the questions were formulated to identify the various noise sources as perceived by respondents in their homes including aircraft noise. The interviews were made personally by this first author supported by the under-graduating students previously trained and the questions were answered by only one informant interviewed for each home in about average´ 30 minutes. The questions were divided into nine distinct parts as listed following: 01) Survey control and questionnaire identification, 02) Household characteristics, 03) Residents profile, 04) Health condition, 05) Informant activities at home, 06) Music preferences, 07) Informant permanence at home, 08) Noise perception, and 09) Informant relationship with Santos Dumont Airport and the aircrafts flying over their households.

### Social survey in progress – 2011

This year a new questionnaire was developed and applied to the same residential sample aiming to actualize the community`s perception about noise. The interviews were performed by phone during March and April, 2011 and the tabulation of these new data is still in process.

All these recent interviewees were made by this first author alone and the answers were collected during the calls` phone directly into the SPHINX´s platform as it was previously prepared. At this time 55 informants completed this new questionnaire and the others 15 informants changed the address or couldn´t be found even by e-mail, phone or mobile phone until now.

SOME RESULTS OF SOCIAL SURVEY 2009


**Figure 1:** Social survey study´s area and Santos Dumont Airport (Google Earth, 2011)

Among the five districts contacted throughout the resident´s associations Santa Teresa collaborated with 38.6 % of the completed questionnaires and it is known this is the most quiet district and its areas are mostly residential comparing to the others four districts. Beyond this Santa Teresa has the more high altitudes among the others studied districts.

**Table 1:** Interviews by district

| Districts | Completed interviews |
|---|---|
| Santa Teresa | 38.6 % |
| Botafogo | 25.7 % |
| Urca | 15.7 % |
| Laranjeiras | 14.3 % |
| Flamengo | 5.7 % |
| Total | 100.0 % |

### About household`s type

Mostly visited household´s (64.3 %) was apartment type and 78.6 % of all were localized bellow five floor. It could be expected that most part of visited households would be localized at higher floors as the highly annoyed people could live at them but it was not confirmed as shown in Table 3. Only 7.1 % of the visited households were covering' floors. About household position from the street the more quiet were lateral or behind but 47.1 % of total homes had the principal façade located in front of the access´ street as shown in Table 4.

**Table 2:** Household´s type

| Household type | Citation |
|---|---|
| Apartment | 64.3 % |
| House | 28.6 % |
| Covering | 7.1 % |
| Total | 100.0 % |

**Table 3:** Floor number

| Floor number | Citation |
|---|---|
| Bellow 0 | 2.9 % |
| 0 to 4 | 78.6 % |
| 5 to 9 | 11.4 % |
| 10 to 14 | 2.9 % |
| 15 to 19 | 0.0 % |
| 20 and more | 4.3 % |
| Total | 100.0 % |

**Table 4:** Household position from the street

| Position from the street | Citation |
|---|---|
| No response | 10.0 % |
| In front | 47.1 % |
| Behind | 32.9 % |
| Lateral | 10.0 % |
| Total | 100.0 % |

## About informants' health

Asked if having or not the health problems disposed in Table 5 the vision problem was related in first place by most residents interviewed. About 64.3 % of the informants related stress problem and 34.3 % related insomnia problem. Only 1.4 % of the informants related diabetes as health problem.

**Table 5:** Informant´s health problems

| Health problem | Yes | No |
|---|---|---|
| Diabetes | 1.4 % | 98.6 % |
| Hearth | 8.6 % | 91.4 % |
| Cholesterol | 11.4 % | 88.6 % |
| Depression | 15.7 % | 84.3 % |
| Digestion | 20.0 % | 80.0 % |
| Hearing | 20.0 % | 80.0 % |
| Breath | 21.4 % | 78.6 % |
| Pressing | 27.1 % | 72.9 % |
| Insomnia | 34.3 % | 65.7 % |
| Stress | 64.3 % | 35.7 % |
| Vision | 71.4 % | 28.6 % |
| Total | 100 % | 100 % |

## About informants' activities and time staying at home

As it is shown at Table 6 more than 50 % of the informants perform frequently or always in home activities that are surely prejudiced by elevated noise levels as reading, listening music/radio, watching TV/DVD, using internet, conversation, using computer, resting, studying or working.

**Table 6:** Informant´s activities at home

| Activities at home | Never | Rarely | Sometimes | Frequently | Always |
|---|---|---|---|---|---|
| Reading | 0.0 % | 4.3 % | 8.6 % | 32.9 % | 54.3 % |
| Listening music/radio | 0.0 % | 10.0 % | 21.4 % | 27.1 % | 41.4 % |
| Watching TV/DVD | 1.4 % | 15.7 % | 20.0 % | 40.0 % | 22.9 % |
| Using internet | 1.4 % | 4.3 % | 7.1 % | 37.1 % | 50.0 % |
| Conversation | 4.3 % | 4.3 % | 10.0 % | 30.0 % | 51.4 % |
| Using computer | 7.1 % | 1.4 % | 11.4 % | 32.9 % | 47.1 % |
| Resting | 10.0 % | 15.7 % | 20.0 % | 20.0 % | 34.3 % |
| Studying | 10.0 % | 17.1 % | 12.9 % | 27.1 % | 32.9 % |
| Working | 11.4 % | 8.6 % | 14.3 % | 27.1 % | 38.6 % |
| Home working | 11.4 % | 14.3 % | 24.3 % | 15.7 % | 34.3% |
| Physical activities | 51.4% | 11.4% | 17.1% | 12.9% | 7.1% |
| Playing musical instrument | 80.0 % | 4.3 % | 7.1 % | 4.3 % | 4.3 % |
| Total | 100 % | 100 % | 100 % | 100 % | 100 % |

During the week days Monday to Friday more than 50 % of the informants used to stay at home frequently or always all the time except among 14:00h and 18:00h schedule as shown in Table 7. In the weekends more than 55 % of the informants used to stay at home frequently or always at all the schedules as shown in Table 8.

**Table 7:** Informant´s schedule staying at home Monday to Friday

| Schedule | Never | Rarely | Sometimes | Frequently | Always |
|---|---|---|---|---|---|
| 7:00h às 12:00h | 8.6 % | 11.4 % | 11.4 % | 34.3 % | 34.3 % |
| 12:00h às 14:00h | 21.4 % | 20.0 % | 7.1 % | 24.3 % | 27.1 % |
| 14:00h às 18:00h | 20.0 % | 24.3 % | 22.9 % | 18.6 % | 14.3 % |
| 18:00h às 22:00h | 0.0 % | 5.7 % | 14.3 % | 37.1 % | 42.9 % |
| 22:00h às 7:00h | 0.0 % | 0.0 % | 1.4 % | 11.4 % | 87.1 % |

**Table 8:** Informant´s schedule staying at home in the weekends

| Schedule | Never | Rarely | Sometimes | Frequently | Always |
|---|---|---|---|---|---|
| 7:00h às 12:00h | 2.9 % | 4.3 % | 7.1 % | 42.9 % | 42.9 % |
| 12:00h às 14:00h | 10.0 % | 10.0 % | 15.7 % | 37.1 % | 27.1 % |
| 14:00h às 18:00h | 5.7 % | 17.1 % | 21.4 % | 35.7 % | 20.0 % |
| 18:00h às 22:00h | 4.3 % | 8.6 % | 14.3 % | 44.3 % | 28.6 % |
| 22:00h às 7:00h | 4.3 % | 4.3 % | 1.4 % | 18.6 % | 71.4 % |

The informants were asked about their perception related to 35 different noise sources including airplanes separating intensity perception and frequency perception. Tables 8 and 9 shows results related to `airplanes` as noise source. So more than 94 % of the informants felt airplanes noise perception as high or very high intensity and 90 % of the informants reported airplanes noise perception frequently or always.

**Table 9:** Informant´s aircraft noise perception - intensity

| Noise source | Noise perception – intensity | | | | |
|---|---|---|---|---|---|
| | Nothing | Weak | Midle | High | Very high |
| Airplanes | 1.4 % | 1.4 % | 2.9 % | 17.1 % | 77.1 % |

**Table 10:** Informant´s aircraft noise perception - frequency

| Noise source | Noise perception – frequency | | | | |
|---|---|---|---|---|---|
| | Never | Rarely | Sometimes | Frequently | Always |
| Airplanes | 1.4 % | 1.4 % | 7.1 % | 21.4 % | 68.6 % |

## NEXT STEPS

In the next stages of this work still in progress it is expected to finalize all the collected data tabulation and their analyses as well as continuing perform the acoustical part of this survey. At the end of all activities the complete model developed throughout this research to approach community perception about airport noise will be published.

**Figure 2:** Airplane overflying Urca´s district during arriving procedure (Raoni Cordeiro's photo, 2009)

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# Mapping of severe annoyance due to aircraft noise

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## INTRODUCTION

The application of generalized exposure-response relations for noise annoyance has expanded enormously in Europe due to the implementation of the European Noise Directive. However, residents often do not recognize themselves in the reported results for their neighborhood or community. “You are not only modeling noise, but also our annoyance; what is wrong with asking us?” and “You are averaging out our annoyance with the use of curves” are comments, which are frequently made.

In this paper we address these comments by exploring whether we can adequately describe the percentage severely annoyed due to aircraft noise in small areas, while making use of routinely collected data, without taking into account modeled noise levels in combination with an existing exposure-response relation. Subsequently, we assessed the role of aircraft noise and other area characteristics on the spatial distribution of severe annoyance.

## METHODS

The study was carried out in the vicinity of Amsterdam Airport Schiphol. The exposure to aircraft noise is modeled every year in an area of 55 by 71 km around the airport. Within this area eight community health services were approached to participate in the study. Once every four years community health services routinely carry out health surveys among adolescents, adults and elderly in the framework of the "Local and National Public Health Monitor" (van den Brink 2011). One of the purposes of this Monitor is to harmonize local data collection methods, in order to obtain data that can be used for comparisons between regions and for calculating national statistics. In the questionnaire distributed to samples of adults (18 to 65 year old) items on noise annoyance are included. For our study we used the data of nine surveys from community health services carried out in the period 2005-2008 in several parts of the area of 55 by 71 km (Plevier & Mulder 2006; GGD Hollands Midden 2006; Heemskerk & Poort 2007; Verhagen & ten Brinke 2007; De Koning 2008; Dijkshoorn et al. 2009; Schütz & Glazema 2009; ten Brink et al. 2009; van Acker 2009). In seven of the nine surveys, the ICBEN standard annoyance question was used (ISO/TS 15666 2003); since 2006 this question is the standard for assessment of annoyance within the Monitor. Severe annoyance was defined as an answer in one of the three highest categories of the 11 point scale of the ICBEN question; a similar definition was used for the questions on annoyance in the other two surveys.

The study design of the Local Monitor is geared to report at the municipal or regional level. For our study we used a smaller aggregation level: the 4 digit postal code area with, on average, about 6,400 inhabitants (range 29-22,500). The variation in aircraft noise levels is small within postal code areas (Houthuijs et al. 2011). Due to privacy reasons only the number of severely annoyed due to aircraft noise and the total number of responders per postal code area were available for the pooled statistical analysis.

The data-set was supplemented with indicators for aircraft noise and with postal code area characteristics (demographic composition, average socio-economic status, address density, and livability index). The $L_{den}$ (Level day-evening-night) and the annual average number of aircraft noise events per day that exceeded a $L_{A,max}$-level of 60 or 70 dB (NA60 and NA70) were modeled by the Dutch National Aerospace Laboratory based on actual flight tracks. In 1.5 million dwellings we assessed the exposure levels by linking the noise maps with the address coordinates. Subsequently, we obtained the “population weighted” mean exposure level by averaging the noise exposure of the dwellings per postal code area. Statistics Netherlands maintains records of the demographic composition and the address density at different aggregation levels online. A measure of socio-economic status (SES) at postal code level based on income level, unemployment rate, and education level of its inhabitants is calculated every 4 years by the Netherlands Institute of Social Research (Knol 1998). The livability index is based on 50 indicators from the domains: house stock, public space, services, social-economic composition, demographic composition, and community safety & neighborhood nuisance (Leidelmeijer et al. 2008).

Due to the small numbers of study participants per postal code area, the observed mean percentage of severe annoyance on this aggregation level can have a high degree of uncertainty. A Bayesian hierarchical model with spatial effects was applied to improve the estimation per postal code area and to map the study area. It was assumed that the number of cases in an area follows a binomial distribution. $p_i$ is an area specific risk, which, in a general form, is given by:

$$\text{logit}(p_i) = \beta_0 + \beta_{1,j}\,\text{Exposure}_{i,j} + \beta_{2,l}\,\text{Confounder}_{i,l} + b_{struc,i} + b_{unstruc,i} \qquad [1]$$

In the equation above, $\beta_0$ is the logit baseline risk. The final two terms consider extra variability resulting from unmeasured confounders, data anomalies, and model misspecification. It is expected that this extra variation is more similar for neighboring areas. Hence, the first term is a spatially structured term for any possible spatially unobserved confounders; the second is an unstructured term accounting for non-spatial contributions to the extra variation. An intrinsic conditional autoregressive prior is given to the spatially structured term. This ICAR prior depends on the number of neighboring postal code areas. An independent and identically distributed normal prior is given to the unstructured term (Besag et al. 1991). In model [1] the parameters for the noise exposure and for potential confounders can be excluded to obtain a smoothed map based on the prevalences only. For Bayesian models MCMC is often used to estimate the posterior distribution of the parameters. This is computationally intensive if the number of areas is high. Therefore we estimated the parameters using INLA (Rue & Martino 2009). The fit of the models was compared using the Deviance Information Criterion (DIC) which indicates a balance between the fit of the data to the model and the complexity of the model (Spiegelhalter et al. 2002).

RESULTS

### Mapping severe annoyance due to aircraft noise

The mean response of the nine surveys was 53 % (range 41-73 %). The dataset consisted of 480 postal code areas with, on average, 60 responders per area (range 1-354), a total of 28,562 study subjects. The responders are, on average, 1.6 % of the age specific population (range 0.6-2.4 % between surveys). The mean percentage of severe annoyance due to aircraft noise in the study area was 9.9 %.

In Figure 1 the average percentage severe annoyance per postal code area is plotted against $L_{den}$.

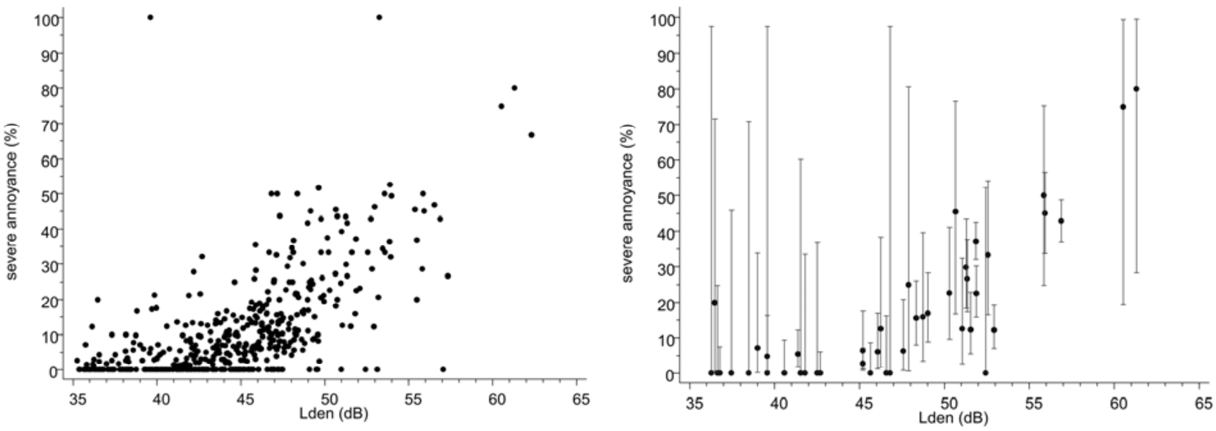


**Figure 1:** Average percentage of severe annoyance per postal code area and $L_{den}$ (left) and with 95% confidence interval (for selection of areas) (right)

The left hand graph of Figure 1 shows large variation between postal code areas. The right part of Figure 1, which includes the 95% confidence interval for a random selection of postal code areas, indicates that the uncertainty of the percentage is large due to the small number of responders. So, a substantial part of the variation between postal code areas is introduced by the sample size per postal code area.

The large variation hampers the plotting of the percentage of severely annoyed on a map; this will give a rather unstable and variable impression dominated by “outliers” due to small numbers. We applied model [1] (without noise and confounders) to improve the estimation per postal code area. The smoothed percentage per postal code area is given in the left hand graph in Figure 2. The “population weighted” mean exposure levels in $L_{den}$ is shown in the right hand graph in Figure 2.

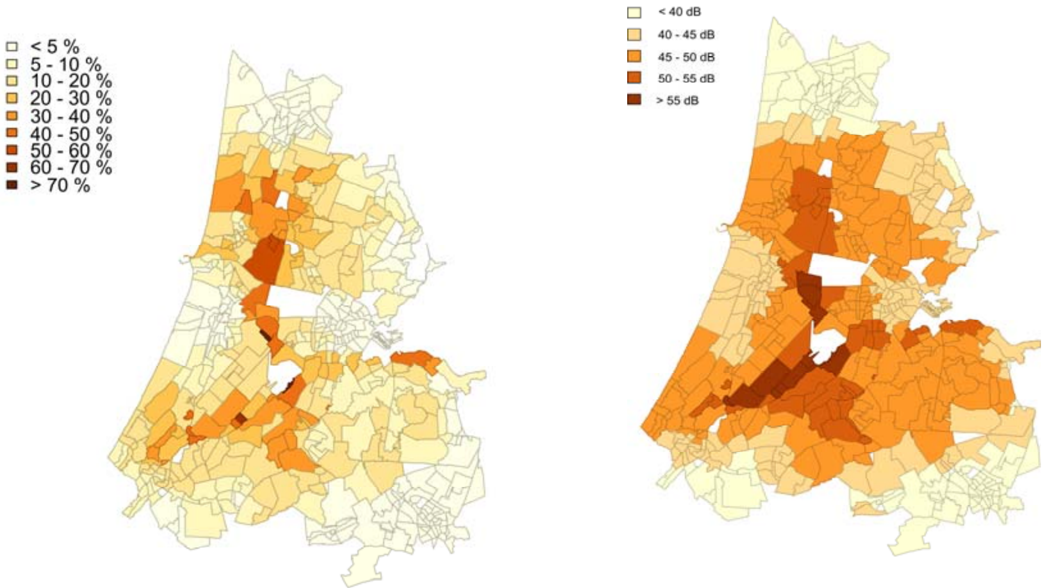


**Figure 2:** Smoothed percentage of severe annoyance and population weighted mean $L_{den}$ (dB) per postal code area

The applied statistical model (without any noise indicator or potential confounder included) leads to a more valid map than plotting “raw” mean percentages of the postal code areas (not shown for this reason). The smoothed percentages in the left hand graph follow fairly the aircraft noise exposure in the study area (right hand graph).

### Influence of aircraft noise indicators and postal code area characteristics

First we assessed the relation between $L_{den}$ and the percentage of severe annoyance. We fitted a non-linear smoothed curve with a second order random walk model to visually check the linearity of the relation between $L_{den}$ and the percentage of severe annoyance on a logit scale (Figure 3).

Figure 3 shows that a linear relation with $L_{den}$ is a good assumption, so it is not necessary to transform the $L_{den}$ to apply model [1]. Moreover, the uncertainty of the estimate substantially increases above 60 dB.

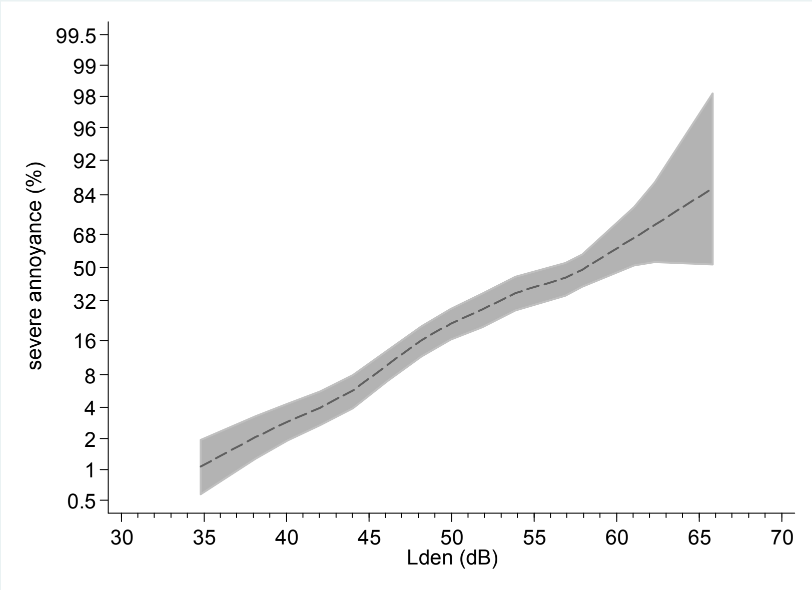


**Figure 3:** Relation between $L_{den}$ and severe annoyance expressed as percentage on a logit scale

Subsequently, we evaluated the influence of the various aircraft noise indicators and the postal code area characteristics with model [1]. The results of these final statistical models are presented in Table 1.

**Table 1:** Association between percentage of severe annoyance and $L_{den}$ and SES expressed as odds ratio [and 95% confidence interval] with and without adjustment for survey

| Adjustment for survey: | $L_{den}$ (per 10 dB) | SES (highest versus lowest) |
|---|---|---|
| no | 9.1 [7.0 - 11.9] | 1.51 [1.11 – 2.07] |
| yes | 9.7 [7.6 - 12.3] | 1.67 [1.23 – 2.27] |

Models with $L_{den}$ as aircraft noise indicator fitted better than models with NA60 or NA70 or of a combination of $L_{den}$ and NA60 or NA70, so $L_{den}$ was incorporated in the final model. The odds ratio for $L_{den}$ in Table 1 is expressed per 10 dB change. When we express the effect of the $L_{den}$ over the exposure range (5 percentile of the $L_{den}$ is 35 dB and 95 percentile is 54 dB: a 19 dB difference) the odds ratio is about 70. From the postal code area characteristics, only SES had an influence on severe annoyance. The prevalence was elevated in postal code areas with higher social economic status. The odds ratio was about 1.6 when we compared the postal code area with the highest SES with the area with the lowest SES. We observed differences in the prevalence of severe annoyance between the nine health surveys. Adjusting for differences between surveys improved the fit of the statistical model, but hardly affected the odds ratio of $L_{den}$ and SES (see Table 1).

In Figure 5 we have mapped the spatially structured term of each of the postal code areas after adjustment for $L_{den}$, SES, and survey.

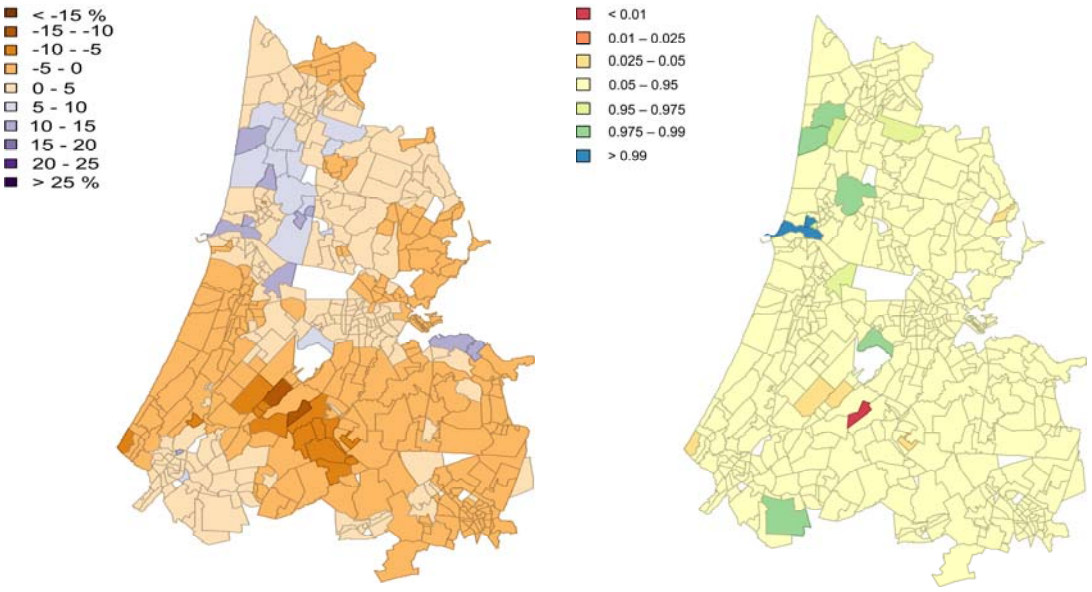


**Figure 5:** Spatial variation between postal code areas after adjustment for $L_{den}$, SES and survey. Left as difference in the percentage severe annoyance; right as probability

The spatially structured term is expressed as deviation from the expected percentage based on $L_{den}$, SES, and survey and as probability. In the left hand map of Figure 5 blue postal code areas have a higher percentage of severe annoyance than expected and earth brown areas a lower percentage. Although the map indicates that substantial differences between postal codes areas exist that might be the result of unmeasured confounders, the right hand map of Figure 5 shows that only in a few cases these differences are statistically significant.

## DISCUSSION AND CONCLUSIONS

The applied statistical method makes it possible to map the prevalence of severe annoyance due to aircraft noise. Although the dataset contained over 28,000 subjects, there are on average only 60 responders per postal code area. As a consequence a substantial part of the observed variation in the percentage of severe annoyance between postal code areas is introduced by the sample size per area. This leads to unstable maps if the percentage per postal code area is plotted. We were able to improve the estimation per postal code area by “borrowing” information from participants in neighboring areas. The advantage of this approach, above the mapping of calculated percentage based on noise maps and an exposure-response relation, is that it allows departures from the exposure-response relation so the local impact of the noise source is more accurately reflected in the map. Another advantage is that it is possible to show the uncertainty in the size of the local deviation: not every local deviation is necessarily a statistically significant difference.

The exposure-response relation obtained with routinely collected (aggregated) data was very similar to the ones found in tailored social surveys with individual data that were carried out by RIVM around the airport in 1996 2002, and 2005 (TNO & RIVM 1998; Breugelmans et al. 2004; RIVM & RIGO 2005). The uncertainty of the relation obtained in the present study increased at higher noise levels. This uncertainty is partly caused by the random selection of the responders over the study area (on average, 1 per 60 residents in the age between 18 and 65 year old). As a result, 16 of the 28,562 responders (0.06 %) lived in a postal code area with a mean noise level above 60 dB $L_{den}$. This small number of participants reflects the governmental policy to limit the number of inhabitants within higher noise contours. However, this low number also leads to concern about the usefulness of routinely collected health data from surveys for the monitoring of the impact of the airport on residents within these contours. Other endpoints than severe annoyance, such as high blood pressure or perceived health, have a much less pronounced relation with noise exposure. Stratified sampling to substantially increase the number of study participants at higher noise levels could overcome this problem.

We found a very strong relation between $L_{den}$ and the prevalence of severe annoyance due to aircraft noise: an odds ratio of about 70 over the 5-95 percentile range of $L_{den}$. Because of privacy reasons, no personal information about the individual study participants was available. Also due to the nature of the health surveys, no information about noise annoyance related factors (like attitude towards the source, noise sensitivity, expectations about future levels, etc.) was collected. At the postal code area level, no specific noise annoyance related data are available. This hampers the possibility to clarify the deviation of a postal code area from the "mean" relation between $L_{den}$ and the percentage severe annoyance. Information about the average number of aircraft noise events per day that exceed an $L_{A,max}$-level of 60 or 70 dB appears not to have much added value when information about the $L_{den}$ is available. In postal code areas with a lower socio-economic status the prevalence of severe annoyance was – at the same $L_{den}$ level - lower than in areas with a high social-economic status. This is opposite to what usually is found for health outcomes. Other postal code area characteristics (demographic composition, address density, livability index) were not associated with annoyance after adjustment for the spatial pattern. We do not expect that the availability of other potential confounders for the postal code areas would have affected the odds ratios for $L_{den}$ or SES. An important advantage of the applied method is that by the incorporation of the spatial dependency in the model, adjustment for unmeasured confounders can be carried out. The applied hierarchical model is very flexible, so it is possible to incorporate potential confounders. Not only at the level of postal code area, but also at other levels of the model (individual, airport, country) with proper estimation of the standard errors of the parameters.

We found that the prevalence of severe annoyance varied between surveys after adjustment for $L_{den}$, SES and the spatial dependency. The health surveys were carried out in different areas, seasons and years. Also different sampling methods and questions were used. We were not able to assess whether one of these characteristics could explain the differences between the surveys. Most of these characteristics were clustered and the number of surveys was small in comparison with the number of differences. Further harmonization of the questionnaires and the methods of data collection are in progress and will improve the comparability of data from community health services in future (van den Brink 2011).

Although the Local Monitor is not designed to report on postal code area level, we were able to map accurately the annoyance due to aircraft noise with our statistical model, without using any exposure-response relation or noise data. The small within area variance of the exposure and its strong relation with severe annoyance facilitated the mapping in the study area.

## ACKNOWLEDGEMENT

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# Trial of a UK-wide support network for low frequency noise sufferers

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## INTRODUCTION

The paper describes the trial of a national network of centers which was set up with the aim of improving the handling of low frequency noise (LFN) complaints. In the UK, noise complaints are usually dealt with by Environmental Health Officers (EHOs), however, in a proportion of LFN cases, perhaps as high as 70 %, no source can be found for the complaint and the EHO is unable to resolve the problem (Waddington et al. 2005; Pedersen 2008). Although LFN complainants are often highly distressed (Berglund et al. 1996; Leventhall 2003) there is generally no route for onwards referral in these 'no source found' cases (see Figure 1).

The hypothesis underlying the study is that, irrespective of the (unknown) cause of the LFN perception, the perception may be lessened through application of techniques specifically adapted from the field of tinnitus and hyperacusis therapy. This hypothesis is supported by current neuroscience models of hearing which are briefly described in the following section. The aim of the project was to establish, on a trial basis, a national network of treatment centers for sufferers of LFN thereby providing a referral route for EHOs in LFN complaints with no obvious origin.

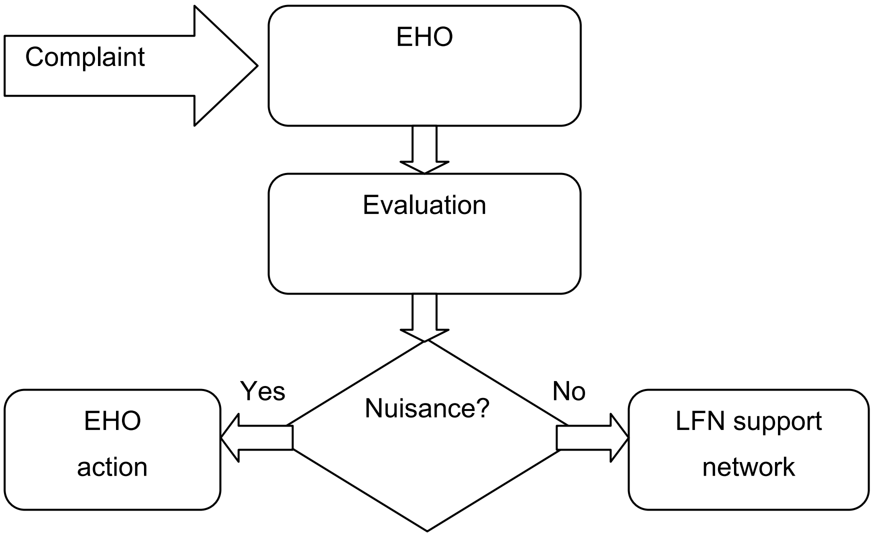


**Figure 1:** Schematic of the path of an LFN complaint

In order to realize this aim the objectives were:

- To identify a network of NHS Tinnitus Clinics that are prepared to assess and treat people with a complaint of low frequency noise in the absence of a measurable signal
- To produce a protocol for the assessment and treatment of such individuals
- To train these centers in methods of the identification of complaints of low frequency noise, low frequency tinnitus, and hyperacusis in this population
- To devise and publicize a pathway for referral of such individuals
- To monitor the operation of the network for a 12 month period
- To report upon the effectiveness of the trial and to make recommendations for future development, or otherwise, of the network

In the following sections we first describe the model of perception, then the setting up of the LFN network. Results of the trials are then presented and discussed.

The results of the trial are described in more detail in the project report (Moorhouse et al. 2011) which is expected to be published during 2011.

## LFN COMPLAINT – AUDITORY NEUROSCIENCE PERSPECTIVE

A modern understanding of human hearing considers not only the traditional auditory pathway, from cochlea to auditory cortex, but also the interfaces between hearing and systems of emotion and reaction. It is believed that these have developed in mammals due to the function of the auditory system as an early warning danger detection system, able to rapidly activate systems of reaction and arousal to an intrusion or potential danger. An underlying proposal of the project was that this understanding of hearing could be mapped on to the experience of LFN complainants, and that this might lead to a novel approach to assistance in that situation.

In the traditional understanding of hearing, inner hair cells in the cochlear respond to sound and synapse with auditory nerve fibers so that the signals are transmitted into the central auditory system. Key structures have been identified within the brainstem concerned with the localization of sound, and within the midbrain with the perceived intensity and importance of sound. The flow of auditory information continues up into the auditory cortex, where meaning is ascribed to sound, and the association cortical areas have function with the interpretation of speech and music.

A modern understanding would also want to consider the connections between brainstem hearing centers and systems of reaction and arousal. Specifically, these involve the sympathetic autonomic nervous system, which instigates a fight or flight reaction to a threatening sound, and the reticular formation, which regulates arousal and sleep under the influence of sound. One only has to reflect briefly to see how fundamentally these interactions between hearing and reaction can influence human arousal and behavior. An example of this is the immediate agitation and arousal associated with thinking one has heard the footstep of an intruder in the hallway when lying in bed at night. These interactions occur below the level of the ascription of meaning in the sense of speech or music, but are able to recognize sound as potentially intrusive of threatening.

This view of human (and mammal) hearing has largely derived from the study of patients with troublesome tinnitus. Such persons can be very agitated and distressed, and the extent of their distress bears little relation to the cause or matched intensity of their tinnitus (see Andersson et al. 2004 for review). Whilst many people who experience tinnitus seem not to be troubled by it, those who exhibit a perplexing mixture of agitation, poor concentration and insomnia, and there is a consensus that this is best explained by models that invoke links between the auditory system and the emotional brain. Whilst there is no one-off intervention that inhibits the tinnitus percept completely and permanently (hence “no cure”), there are therapies involving sound, counseling and relaxation that can improve quality of life in such cases. What such approaches hold in common is their invocation of the principle of habituation. The components of therapy for tinnitus are: understanding the causes of distress; management of the reaction, for example using relaxation therapy; sleep management, sometimes called ‘sleep hygiene’.

Another symptom that is often associated with tinnitus is that of hyperacusis, in which a person finds that sound intensities that many people can easily tolerate are uncomfortably loud and distressing. It is presently thought that the central sensitivity of the auditory system is dynamic: meaning that it can change according to the sound environment. Thus in very quiet surroundings auditory sensitivity (or gain) is maximized, and in louder surroundings it is minimized. In persons with hyperacusis the proposal is that central auditory sensitivity is consistently on maximum, and unable to change dependent upon surroundings, so that sound of even moderate intensity is perceived as loud and distressing. The discomfort evoked may make the person distressed and anxious (modulated by the sympathetic nervous system), which further increases the sensitivity of the auditory system.

It will be apparent that there are some marked similarities between the experiences of troublesome tinnitus and hyperacusis, and of complaint of LFN in the absence of any measureable stimulus. The distress may be substantial, and involve agitation, anxiety and irritability. The signal itself may be small, or may be the perception of unremarkable levels of environmental LF sound exacerbated by increased central auditory gain. It appears that there may be a vicious circle between the LF perception and the distress that this evokes (see Figure 2). As with tinnitus and hyperacusis there is no suggestion that either the person’s belief that they are experiencing significant LF noise, or that the distress evoked are not genuine: clearly they can both be very substantial and life defining. This understanding of LFN complaint suggests that it may be possible to develop a specific treatment protocol which will be discussed further in the next section.

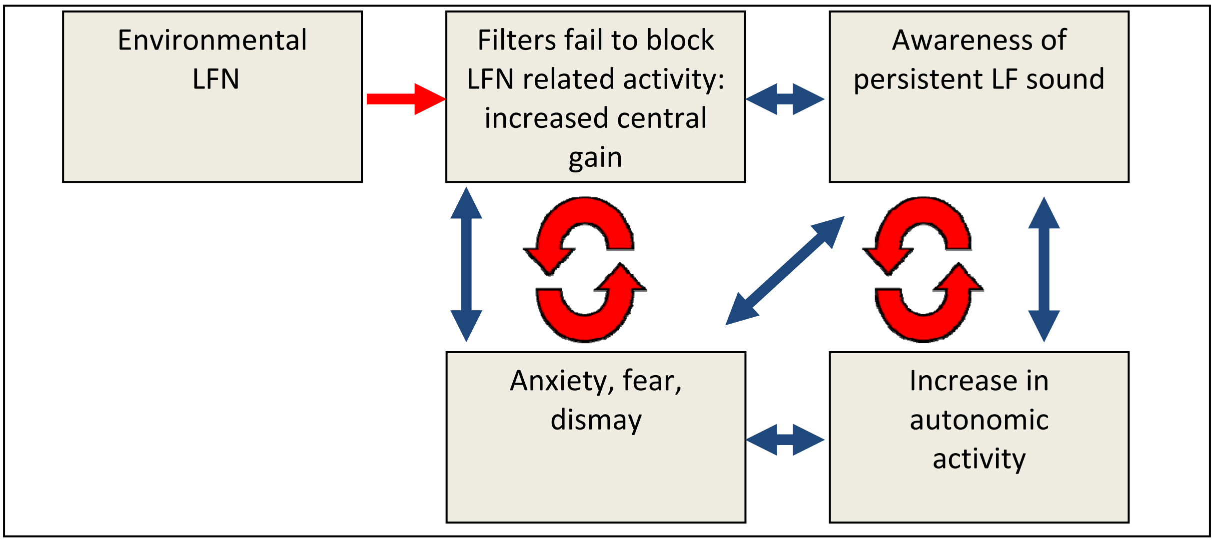


**Figure 2**: Schematic diagrams of the development of distress and arousal to perceived LFN. Adapted from McKenna et al. (2010)

THE LFN NETWORK

**Centres**

Letters were sent to 289 Audiology centers within the NHS (National Health Service) inviting recipients to take part in the trial and requesting information on the number of tinnitus, hyperacusis and LFN cases seen per year. Six centers were initially selected to form a network which was subsequently increased to nine centers located as shown in Figure 3.

**Figure 3:** The LFN network

The relatively high rate of positive responses (13 %) was taken to indicate a willingness amongst audiologists to engage with LFN complainants. The mailshot results also produced some interesting statistics about the number of LFN complainants already within the NHS: excluding one outlier a total of 34 recent LFN cases were reported, an average of 1.1 per therapist per year. If this number were repeated for all active therapists then the total number of cases would be around 160 per year. In fact it seems likely that those taking an interest in the survey were more likely than average to have seen LFN complainants so this figure is likely to be on the high side. Even so, it is still lower than previous estimates of the number of LFN complaints (see Tempest 1989).

Once established, each audiologist made contact with EHOs within their area making them aware of the study and inviting participation of LFN complainants in cases where no source could be found or where the LFN was below actionable levels. The complainants were offered the chance to participate and upon acceptance were routed via their doctor (GP) to the audiology service. In some areas, where too few subjects came forward, the catchment area was widened so as to include more local authorities. Despite concerns that the offer of treatment would cause a ‘flood’ of LFN cases, in reality the opposite proved to be the case, and the number of referrals was lower than expected, with 14 subjects taking part, 11 of which were referred by EHOs and 3 of which were self-referred.

**Treatment protocol and outcome measures**

In collaboration with the participating audiologists a treatment protocol was developed the main elements of which were:

- The exclusion of treatable disease by clinical history, otoscopy, audiometry and ENT opinion as local protocols dictated
- Discussion of the distress and agitation evoked by the perceived LFN
- Environmental sound therapy to reduce the starkness of the signal
- Relaxation therapy to reduce the arousal and agitation associated with the signal
- Identification of those individuals with clinically significant anxiety and/or depression and referral to Psychological Services (using the Hospital Anxiety and Depression Scale; Zigmond & Snaith 1983)

Training for the participating therapists was provided two one-day workshops and included: sharing of experience and good practice, background in how LFN cases are handled, description of the auditory neuroscience model of LFN, introduction to the treatment protocol.

Regarding outcome measures, at the present time there is no specific questionnaire for LFN complaints available and so a selection of validated questionnaires were selected that each catch one aspect of the LFN complaint experience. These were:

a. Hospital Anxiety and Depression Scale (HADS) questionnaire (Zigmond & Snaith 1983)

b. Tinnitus Handicap Inventory (THI) questionnaire (Newman et al.1996), but substitute LFN experience for the concept of tinnitus

c. Hyperacusis was measured using a validated 14 item self-report questionnaire (Khalfa et al. 2002).

d. EQ−5D questionnaire (EuroQol—an instrument for the measurement of health-related quality of life. The EuroQol Group 1990)

e. Visual analogue scales for: LFN loudness, pitch and distress.

Items a, c and d are validated self-report questionnaires measuring respectively, anxiety/ depression, hyperacusis and general quality of life. Item b is a validated questionnaire to measure the handicap due to tinnitus, but the words ‘Low Frequency Noise’ were substituted for ‘tinnitus’. Item e was developed specifically for the study in order to measure loudness and pitch of the LFN pre and post treatment, as well as the level of distress. They consisted of an unmarked scale with marked end points labeled, low/ high pitch, very quiet/ loud, not at all/ extremely (distressing).

## RESULTS OF TRIALS AND EVALUATION

The intended benefits were (a) improved quality of life for sufferers and (b) improved use of resources for EHOs. These aspects are discussed under separate headings below. The use of audiologist-based and computer-based therapy protocols is also briefly discussed.

### Evaluation of benefit to LFN complainants

The audiologist's case notes also provided interesting qualitative data. For example, as might be expected in a group of this age profile, it was found that some, although not all, had previous health issues such as whiplash, labyrinthitis, neurosurgery, seasonal affective disorder (SAD). Sleep disturbance was common and several subjects reported it to be 'draining' and tried to avoid being in the home as much as possible. Such reports are broadly consistent with other descriptions of LFN (Leventhall 2003).

However, the main instrument for measurement of the potential benefit consisted of the questionnaires as described in the previous section. A total of seven separate outcome measures were evaluated with the various questionnaires.

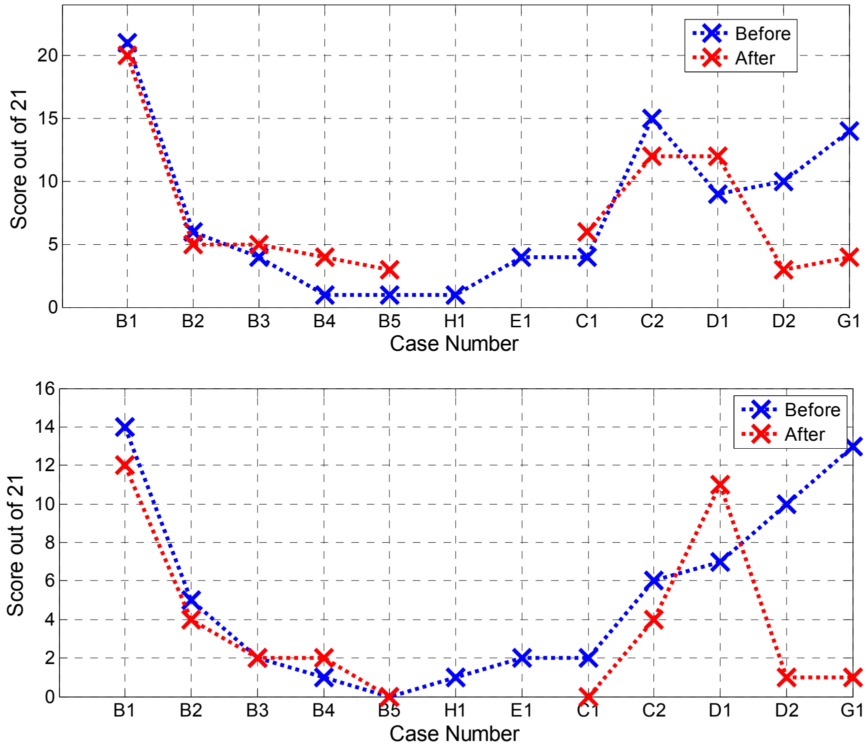


**Figure 4**: Hospital Anxiety and Depression Scale (HADS) scores: upper – anxiety, lower - depression

Example before-after comparisons are shown in Figure 4 for the HADS anxiety and depression scales. The results are mixed with some subjects indicating a marked improvement (D2, G2) and others showing little effect or even a slight worsening.

A single-sided, paired t-test of the seven indicators for the subjects available to date revealed that the means of all seven had moved in a favorable direction but that the improvement was only significant at the $p<0.05$ level for two of the indicators. Thus, more subjects would be required to confirm the benefit.

Metrics of distress and handicap all indicated a clinical population that was agitated and distressed by their situation, and self-report of length of complaint evidenced a situation that was chronic and long-standing. Whilst not large in number, those individuals with LFN complaint have a significant clinical need.

### Evaluation of benefit to EHOs

The benefit to EHOs was evaluated by means of a semi-structured interview over the telephone. Generally it was felt that the number of referrals had been too small to tell whether it has really gathered momentum. However, all EHOs were very positive about the service and wanted it to continue because such cases were felt to be stressful and resource-intensive. It was felt to be good to be able to offer another option for people and there are pro-active authorities who now see it as part of their health and wellbeing strategy.

A number of useful signposts for future developments have emerged from this evaluation, specifically that raising awareness amongst doctors and EHOs would be beneficial. It was also suggested that awareness amongst audiologists could be achieved with articles on key websites such as those of the British Tinnitus Association (BTA), Institute of Acoustics (IoA) and perhaps the Royal National Institute for the Deaf (RNID).

### Audiologist vs computer based therapy

In the recent study of Leventhall and colleague (Leventhall & Robertson 2009), a computerised Cognitive Behavioural Therapy (CBT) course was applied to persons suffering from LFN exposure. Statistically significant improvements in a questionnaire measure of coping ability were demonstrated, though there was a significant drop-out rate (13 of 40 individuals who started the course, 33 %, or 26 of 53 enquirers, 49 %), and an intention to treat analysis (e.g. considering drop-out subjects as if they had no change after treatment) was not performed. The authors noted that among the drop-outs were some of the most distressed individuals, and that these persons might need “special attention and extra help” (p57) to be able to access therapy. Those that completed the course were thus a self-selected group to whom this approach was acceptable. Even so, it appears that computerized CBT has a value in the LFN complaint population.

This is germane to the present study, in that it is potentially possible that the audiologist-based approach reported here could be combined with a computer-based approach. The present study indicates that Audiology based therapy provides a context in which people with LFN complaint can be assessed, treatable audiological conditions can be excluded, and where some (modest) improvement can be made in some individuals. Individuals with high distress can be identified, and support put in place for them. If one considers that the high levels of stress in this patient population may be a factor that reduces the efficacy of intervention, then the use of computer based CBT may be beneficial in addressing that aspect of the LFN complaint experience. Further research is needed to consider this possible approach to optimizing interventions for this group of people.

## CONCLUDING REMARKS

There is a willingness of the audiology community and tinnitus specialists in particular to engage in LFN cases. However, fewer cases than expected were referred and estimates of incidence rates suggest that the complainant numbers are relatively low.

From the EHO perspective, although there seemed to be some initial difficulty in forming a working relationship with an audiologist, the EHOs who had made referrals were generally very positive about this possibility and wanted the scheme to continue. It is clear that LFN cases require significantly more resources than other noise complaints and that the opportunity to refer to a more qualified specialist (and to help the complainant) could help to reduce this burden.

The benefits of the treatment protocol to LFN complainants, the mean outcome measures from all seven separate outcome measures (questionnaires) moved in a favorable direction which suggests an overall improvement. However when viewed separately, statistical significance was only achieved for two of these measures (and then at the $p<0.05$ level rather than $p<0.01$). A larger statistical sample would therefore be required to confirm the benefits.

The model proposed of stress and increased auditory gain is a plausible explanation for the symptoms noted in LFN cases. In particular, the involvement of the sympathetic autonomic nervous system, and of the emotional brain, is likely to be a faithful representation of the clinical situation.

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# Assessing the impact of blast noise on communities near U.S. Army installations

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## INTRODUCTION

In the United States, the number of people living near military installations is steadily growing. Land that was once sparsely populated is seeing a drastic increase in development. This suburban sprawl, combined with the escalation of military activities over the past decade, has heightened the potential for noise generated by U.S. military installations to negatively impact the surrounding communities. One of these sources of noise, military blast noise, has for many years been the cause of community disturbances around and legal actions against U.S. Army installations. Blast noise—the noise generated from large weapons, artillery, and explosions—is unique in that it is both impulsive and high energy, with the majority of the sound energy being concentrated from 10–100 Hz. Because of the high levels at low frequencies, blast noise is notoriously difficult to mitigate and can propagate long distances with minimal attenuation. The noise footprint from any blast-creating training or testing exercise on an installation thus has the potential to extend many tens of kilometers into the surrounding communities. Furthermore, due to the strong dependence upon immediate atmospheric conditions, this footprint can be highly anisotropic—levels in opposing directions can vary by as many as 50 dB un-weighted peak level (ZPk), so while one neighborhood may be barely able to hear the blasts, another may be exposed to peak levels in excess of 130 dB ZPk. To compound the problem, blast noise occurs intermittently; there are typically short periods of intense activity followed by long periods of relative silence, and so relating average noise levels to community response reveals an inaccurate picture of how blast noise is impacting the community on a daily, weekly, or even monthly time scale.

Nevertheless, to assess the impact of these activities on the surrounding communities, U.S. military noise impact standards are currently based on the percent of the population highly-annoyed (%HA) as a function of the C-weighted yearly average noise level (CDNL) (Department of the Army 2007), similarly to the %HA-ADNL relationship that is used to assess transportation noise impacts (Schultz 1978). Army regulations also recommend supplementing this metric with single event peak measurements to predict the risk of receiving blast noise complaints. Neither method, however, fully meets the United States Army's noise management needs and has proven unsatisfactory for predicting both blast noise annoyance and complaints. This is not a moot point; both large and small-scale complaint actions and community annoyance have resulted in the cessation or postponement of testing and training activities, and in some cases have closed down active ranges altogether. More adequate prediction and assessment methods are therefore necessary to protect public welfare and quality of life, while at the same time maintaining the combat readiness of troops.

To address this problem, a large-scale field study is underway at three U.S. military installations. Four research protocols are employed in this project: personal interviews with residents living near the installation, a survey of complainants and their neighbors, a general survey of the community surrounding the installation, and a detailed study of a small number of residents' responses to single blast events *in situ*. The aim of this paper is to provide an overview of each aspect of this project and provide an update on the results obtained since those presented at ICBEN 2008. As noted in 2008, all findings in this project thus far indicate that the number, timing, and level of discrete blast events are important for predicting the human response to blast noise. More recently, and perhaps more importantly, we have demonstrated that there is a large spatial variation in both noise environment and annoyance to blast noise, and that current noise metrics correlate poorly with annoyance.

## OVERVIEW OF RESEARCH PROTOCOLS

### Personal interviews

In order to determine the language that residents used to describe noise in their environment, and to validate concepts that were subsequently used in the *in situ* study and general community annoyance survey instruments described below, a series of personal interviews were conducted with residents living around 3 U.S. military installations. These installations were located in three geographically different regions (Northeast US, Southeast US, and Western US), to ensure there were no local dialect or language differences. In total, 26 interviews were conducted. The interviews were recorded, transcribed verbatim, and qualitatively compared for common observations, terminology, and types of complaints.

### Complaint survey (correlation of complaints and annoyance)

Although decisions made by an installation regarding whether to suspend activities or close facilities due to noise are typically driven by complainants, there is still some debate as to whether complainants can be used as measures of general community annoyance (Fidell 2003; Maziul et al. 2005; Nykaza et al. 2005). To investigate this in detail, a survey of complainants and their neighbors was performed. Each time a complaint was registered to one of our participating installations over a 7 month time period, the complainant and 9 neighboring households were telephoned and asked to participate in a survey. The survey asked a total of 43 questions, including two annoyance questions, a variety of questions about the respondents' neighborhood and environment, and specific questions about the complaint-related blast event (CRBE). The survey used the set of noise-reaction questions recommended by ICBEN, although to reduce the burden on respondents, only the 5-point verbal reaction questions were asked. The complainant-matched samples were chosen based on proximity to the complainant's household under the assumption that these individuals would have been exposed to approximately the same noise environment. The study results, full survey instrument, and further details regarding the methods for this study can be found in Nykaza et al. (2011).

### General community survey

To determine how blast noise levels affect general community annoyance and how this reaction changes over time, a General Community Survey (GCS) was administered to individuals living in close proximity to the installations. The GCS consisted of a cross-sectional sample of individuals composed of different households each time, as well as a panel sample of households composed of the same households surveyed at different times. Whereas the cross-sectional survey was designed to examine the general community response as a function of time, the panel sample was designed to illuminate changes in the individual households' responses over time. The survey was administered over a 9-month period, with a target of approximately 50 respondents being surveyed each month for the cross-sectional portion of the survey. The panel sample was designed to re-interview up to 150 individuals in months 6 through 9 who were first interviewed in months 1 through 3 (a random subset of 50 from each of the first three months). This paper will only present preliminary results from the cross-sectional survey at the first of three study sites.

The GCS was developed in conjunction with and is very similar to the survey used in the Complaint Survey protocol. The GCS, too, asked a total of 43 questions. The categories of questions on the survey included questions of annoyance to noise sources over the past 4 weeks and 12 months, as well as general questions about the neighborhood and environment, the importance of the installation to the respondent/community, and the characteristics of the respondent household. Noise data for the corresponding 9-month time period were recorded by an array of noise monitors surrounding the installations, and levels were extrapolated to each respondent's household using these data. In this way, the approximate blast noise environment of each respondent could be assessed.

To date, the survey has been completed in communities near two installations. At the first installation, 771 total surveys were completed. At the second installation, 661 surveys were completed. The GCS for the third installation is scheduled to commence in the fall of 2011.

### ***In situ*** **study**

The protocols described above were aimed at obtaining a general view of the community's response to blast noise. To improve the current assessment procedures, however, what is arguably needed is more data regarding how *individuals* respond to individual blast events as they go about their daily lives. To address this, individual community members were recruited and their homes instrumented with microphones outdoors, indoors, and accelerometers on the windows and foundation. The accelerometer data are important for developing metrics that can subsequently be related to rattle, which has previously shown to affect noise complaints (Luz et al. 1983; Schomer 1978), laboratory judgments of blast annoyance (Schomer & Averbuch 1989) and homeowner judgments of actual blasts (Luz 1994). Each individual participates for 3 months. The system is triggered by events exceeding 100 dB ZPk; 5 seconds of acoustic and vibration data are collected for *each* event occurring within the 3 month participation period. In addition to the noise and vibration data recorded, the participants are asked to fill out a short web-based survey (employing the ICBEN 11-point annoyance scale) each time they hear a blast or a series of blasts, thus providing immediate responses to events via time-tagged questionnaires. Residents are also asked to fill out the same survey at the beginning and end of each day, to obtain cumulative day and night annoyance measures. At the first installation, 36 individuals were recruited and data collected over the course of a year. Another 32-36 individuals are planned for the second installation, which will start collection in the fall of 2011.

## RESULTS TO DATE

### Personal interviews

The main objective of the personal interview protocol was to capture the language that residents living around Continental United States (CONUS) military installations use to describe their community, environment, and noise in their own words. It was found that the residents in all three regions used similar language to describe their environment, noise in general, and blast noise in specific. In addition, their language was similar to the language used by the research community (e.g., the language in scientific presentations and papers), and most importantly, to the survey questions that were designed for all of the protocols encompassed within this large field study effort.

The interviews also uncovered that the majority of residents are aware of the installation and the noise it produces, like their community and neighborhood, do not notice quieter military noise events, but do notice loud events and events that induce rattle and vibration. A comparison of the percentage of the respondents mentioning the content categories given in Luz et al. (1983; Table 1) was not significantly different than responses given in Luz et al. (1983) and Nykaza et al. (2008). Approximately half of the residents mention rattling and vibration and one-third of the residents mention annoyance and fear of damage to one's home.

**Table 5:** Content categories and percentage of respondents mentioning content (from Luz et al. 1983)

| ***Content category*** | ***% Respondents Luz et al. (1983)*** |
|---|---|
| Vibration, rattling, shaking, etc. | 54 |
| Putative, fear or actual damage to house | 32 |
| Objectionable, irritating, annoying sound | 30 |
| Objects falling from shelves or walls | 14 |
| Sleep disturbance | 13 |
| Disturbance of children | 10 |
| Disturbance of animals | 5 |
| Fear/physiological distress/adverse health effects | 4 |
| Damage to wells | 2 |

### Complaint survey (correlation of complaints and annoyance)

The main objective of the complaint survey was to get a better understanding of the relationship between individuals' complaint response and community's annoyance response to blast noise. Two annoyance questions were asked in this study; annoyance to the complaint-related blast event (CRBE) and annoyance to general military noise. In both cases it was found that those who file complaints (complainants) were more annoyed by noise than those who do not (non-complainants - also referred to as "matched-sample"). That is, complainants were more annoyed than their neighbors who were home at the time of the CRBE (Figure 1a), and in general complainants were more annoyed to general military noise than the non-complainants (Figure 1b). As shown in Figure 1b, the mean annoyance between complaint statuses increased as the number of reported complaints increased. That is, there was an increase in mean annoyance between those who did not file complaints (non-complainants), first time complainants, and repeat complainants. A similar increasing response with complaint status trend was found with noise sensitivity (not shown).

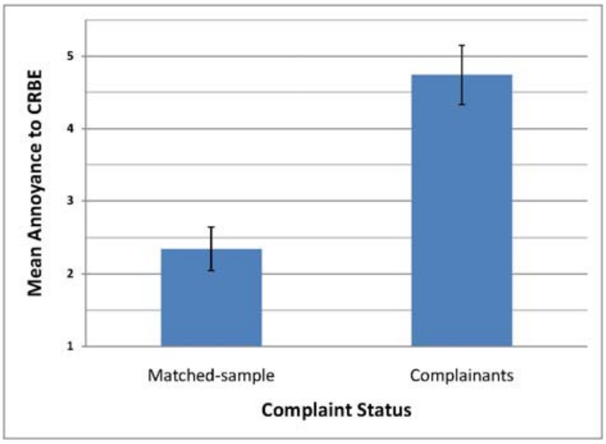


**Figure 1a:** Mean annoyance of complainants and their neighbors in regards to the CRBE

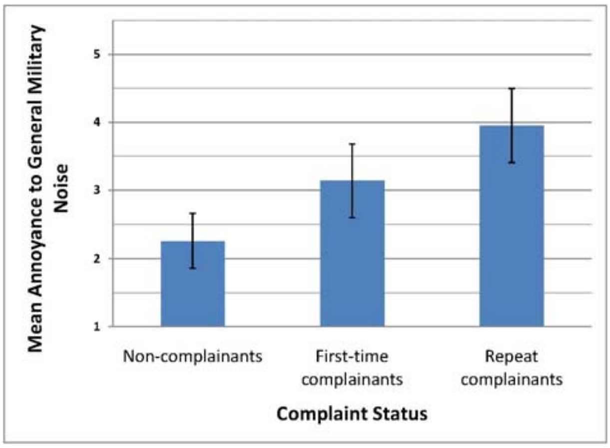


**Figure 1b:** Mean annoyance of first-time and repeat complainants as compared to their neighbors in regards to general military noise

This study also looked at the correlation among response variables and reported annoyance. It was found that, regardless of complaint status, those who reported higher annoyance to general military noise typically reported that their neighborhood was noisy, felt that the installation had little importance on local economy, and were more noise sensitive than those who report less annoyance.

In viewing all of the respondents together, it was found that 89 % reported hearing military noise, 84 % rate their neighborhood as a good or excellent place to live, and 68 % report that their neighborhood is quiet. Of the respondents that were home during the CRBE, 87 % mentioned rattle or vibration and 78 % of those respondents reported that their windows rattled.

### General community survey

The objective of the general community survey (GCS) was not only to look at the correlation between community response (i.e., annoyance) and the blast noise environment, but to answer the question of whether the annoyance response to blast noise changes as the noise environment changes. For the 9 months data collection at study site 1, it was found that both the annoyance response and the blast noise environment change over time; that is, the mean annoyance to blast noise over the 4 weeks preceding the survey varies temporally along with the C-weighted Day-Night Level (CDNL) calculated from all blast events in that time period (data not shown). In general, there was a weak correlation between annoyance response and some of the most common blast noise metrics, e.g., CDNL, number of shots above a given unweighted peak level, and sound exposure level (SEL) (Table 2). Mean annoyance also varies spatially, as expected due to the anisotropy in blast noise propagation (Figure 2). Interestingly, the spatial variation of blast noise annoyance differed from that of military aircraft and all other noise sources addressed in the survey.

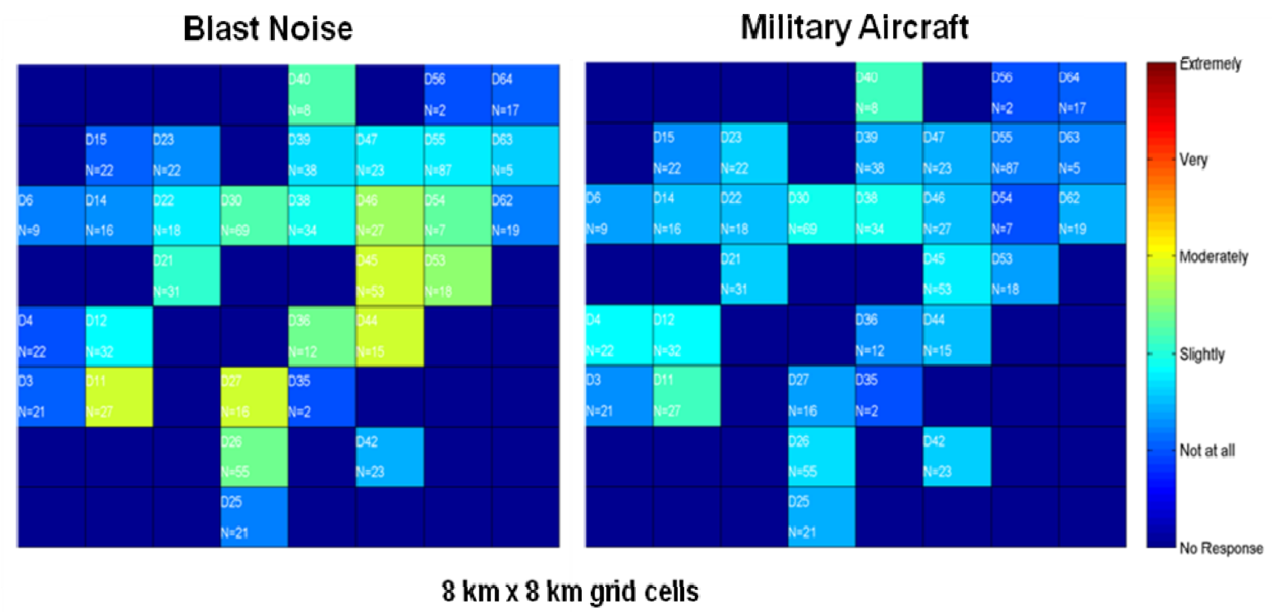


**Figure 2:** Spatial variation of mean annoyance for blast noise (left panel) and military aircraft (right panel). Numbers of respondents are shown in each grid cell. Each area is an 8 km x 8 km area. The installation is located approximately in the center of each plot.

**Table 6:** Raw correlations between annoyance over the specified time period, and the corresponding noise metric for that same time period

| | Number of blasts above 110 dB $Z_{pk}$ | Number of blasts above 115 dB $Z_{pk}$ | CDNL | Maximum un-weighted peak level ($Z_{pk}$) | Maximum CSEL |
|---|---|---|---|---|---|
| **12 month annoyance** | 0.32 | 0.31 | 0.31 | 0.19 | 0.18 |
| **4 week annoyance** | 0.18 | 0.12 | -0.01* | 0.16 | 0.15 |

*not significant at the 0.05 level

Among all the noise sources that survey respondents at site 1 were asked to rate their annoyance, blast noise was the most annoying (Figure 3). Further, those who self-report having a high propensity to habituating to noise have a lower mean annoyance to all noise sources than those who self-report having a low propensity of habituating to noise.

Some other interesting findings from the survey were that most respondents report that they can adapt to noise over time and believe that most other people can adapt to noise over time. It was also found that most residents were aware of the installation and the noise produced by the installation before they moved into the area, would not consider moving because of noise, and felt that blast noise does not interfere with conversation. For a more detailed discussion of this study, including analysis methods and results, readers should refer to the project website:

http://www.serdp.com/Program-Areas/Weapons-Systems-and-Platforms/Noise-and-Emissions/Noise/WP-1546

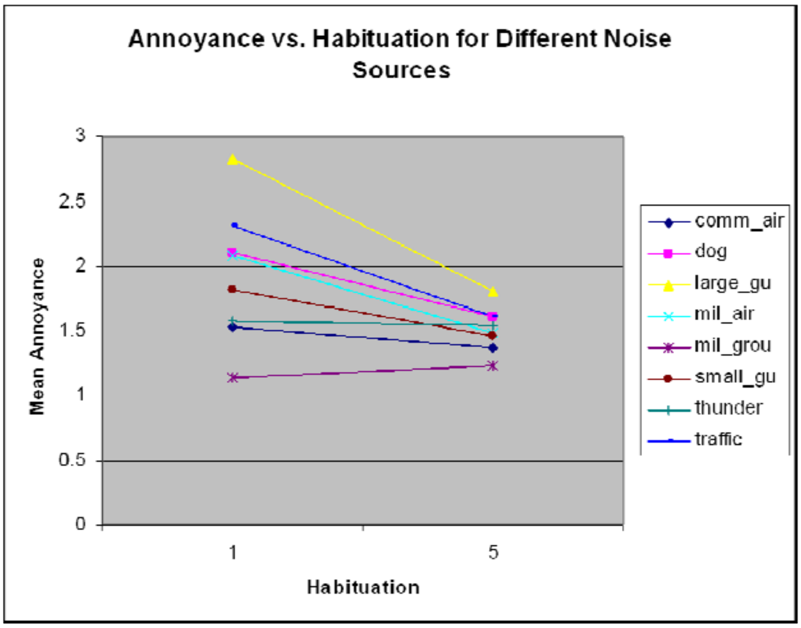


**Figure 3:** Mean annoyance vs. self-reported habituation. Results from an ANCOVA showed a signficant interaction between noise source and habituation. In addition, blast noise ("large_gu" in the legend) was the most annoying noise source out of the 8 on the survey, and seemed to be a source that respondents felt could be habituated to most easily.

## ACKNOWLEGEMENTS

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# The adapted Vos' model to predict total noise annoyance due to an industrial noise with a main spectral component in middle frequencies combined with a background noise

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## INTRODUCTION

Noise from industrial sources such as ventilation systems may cause considerable concern, even at low or moderate sound pressure levels (Berglund & Lindvall 1995). A previous study (Alayrac et al. 2010) has highlighted that different indicators, led by spectral feature type, are necessary to predict noise annoyance due to exposure to various steady and permanent industrial noises. However, when people live close to an industrial plant, they are exposed to a combination of industrial noise and background noise due to other noises in the environment. The current study, a part of Alayrac's PhD work (Alayrac 2009; Alayrac et al. 2011), focuses on determining total annoyance indicators in laboratory conditions for different ambient noises composed of one industrial noise and a background noise.

The type of industrial noises, the type of background noises and the sound emergence level of the industrial noise (Viollon et al. 2004) have a significant effect on noise annoyance. The sound emergence level is an index used by the French legislation standards to assess the noise impact of industrial noises; it is the difference between the A-weighted sound pressure level of the ambient noise (combination of industrial noise and background noise) and the A-weighted sound pressure level of the background noise (AFNOR NF S 31-010 1996). Concerning background noise, some previous works (e.g. Lim et al. 2008) concluded that the background noise has a significant effect on annoyance judgments for aircraft noises, whereas other studies (e.g. Fields 1998) did not support this conclusion. Consequently, the effect of the type of background noise, the type of industrial noise and the sound emergence level of the industrial noise are studied to assess noise impact of industrial plant and to propose total noise annoyance indicators.

This communication is organized as follows. Firstly, the experimental procedure carried out is detailed. Secondly, the assessment of total annoyance indicators is described. Finally, the conclusions are given.

## EXPERIMENT

### Stimuli

The industrial noises were studied in Alayrac et al. (2010). They were recorded in the vicinity of the sources using a stereophonic system (ORTF technique) and filtered to take into account one situation of noise propagation between the recording point and a virtual dwelling.

The industrial noises contain several spectral components with a main component centered at various frequencies between 200 Hz and 1 kHz. Two spectral features with an effect on specific annoyance were identified: the number of spectral components and the energy distribution between low and middle frequencies (Alayrac et al. 2010). Four noises with different values for these features were selected for the current study: IN_1, IN_2, IN_3 and IN_4 (see Fig. 1). They were emitted by pumps and gas flow mechanical devices.

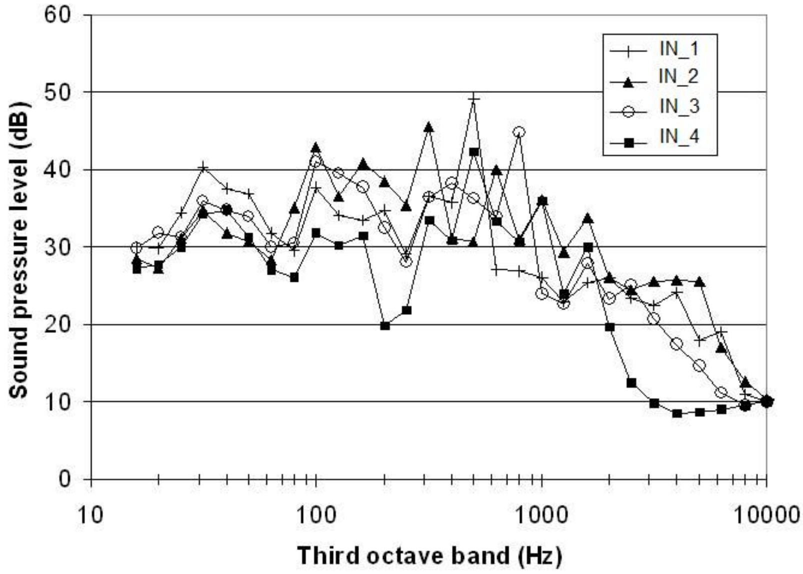


**Figure 1:** Sound pressure level spectra of the industrial noises with a main component in middle frequencies (global sound pressure level set at 45 dB(A))

Five background noises recorded with the stereophonic system were selected to test different sound environments where residents around an industrial plant could live. The background noises were reproduced at a unique sound pressure level (SPL) corresponding to their recording level. These background noises were: **nature** (quiet area with brook and birds; denoted by **NA**) set at 37.5 dB(A), **residential area** (quiet area with birds; denoted by **RE**) set at 38.5 dB(A), **city** (quiet street; denoted by **CI**) set at 45 dB(A), **building site** (noisy area; denoted by **BU**) set at 49 dB(A) and **road traffic** (road traffic noise recorded at 400 m; denoted by **RO**) set at 51 dB(A).

The studied ambient noises were composed of one industrial noise and one background noise. The sound emergence levels of the 4 industrial noises are set at 8 values, from 1 to 8 dB(A) in 1-dB(A) steps, for each background noise (NA, RE, CI, BU and RO). Therefore, 165 stimuli are proposed. The stimulus duration was 7 s.

## Scaling method

Annoyance studied here in laboratory is understood as short-term annoyance (cf. (Berglund et al. 1975)). The scaling method relies on recommendations from Fields et al. (2001) and the ISO standard 15666 (2003). The following instructions (in French for the test) were given to the subjects: “Imagine yourself being exposed to this environmental noise at home 24 hours a day. How much does this environmental noise annoy you?” Subjects answered on a continuous scale with numerical labels equally spaced from 0 to 10 and 5 verbal labels (from “not at all”, “slightly”, “moderately”, “very” to “extremely”) to facilitate the use of the continuous scale. The stimuli were presented one by one in random order by type of background noise.

### Procedure

The listening test was composed of 2 sessions separated by 5-minute break. One session concerns specific annoyance due to the industrial noise studied in (Alayrac et al. 2010). Each session lasted 15 minutes on average. A training test with 11 stimuli was conducted.

### Subjects

Thirty subjects (15 men, 15 women; 18–60 years old) participated. All declared normal hearing abilities. Subjects were paid for their participation.

### Apparatus

The reproduction was performed in a quiet room (background noise level around 20 dB(A)) using two loudspeakers (Tannoy System 1200) and an MC² T500 amplifier connected to a high-quality sound card (DIGIGRAM UAX220) of a computer located in another room. The stimuli were recorded at the point of the listener's ear using two 1/2" omnidirectional microphones. Acoustic and psychoacoustic indices were calculated to assess noise annoyance indicators.

### Analysis

The statistical analysis was performed using STATISTICA software (Statsoft, Inc.). Analyses of variance with repeated measures (repeated-measures ANOVA) were conducted. The data were checked for normality and sphericity (Howell 1998). The identification of significant differences between factor levels was assessed using Tukey's honestly significant difference (HSD) test. Regression models were developed using generalized linear models. To confirm the accuracy of the model, the model fit was calculated and the normality and the homoscedasticity of the residuals were checked (Bech & Zacharov 2006). The annoyance predicted from the tested models was compared with the measured annoyance, by calculating correlation coefficients.

## RESULTS

### Acoustical factors influencing total annoyance

A repeated-measures ANOVA is conducted on three factors: the type of background noise (5 levels for this factor), the type of industrial noise (4 levels for this factor), and the sound emergence level of the industrial noise (8 levels for this factor). The influence of the type of background noise prevails in annoyance response ($F(4,116)=137.16$; $p<0.001$), contributing to 45.1 % of the variance, in comparison with the sound emergence level of the industrial noise ($F(7,203)=187.63$; $p<0.001$) and the type of industrial noise ($F(3,87)=34.08$; $p<0.001$) that respectively contribute to 7.6 % and 1.1 % of the variance. Weak but significant interactions influencing total annoyance are observed between the type of industrial noise and its sound emergence level ($F(21,609)=6.62$; $p<0.05$; explaining 0.4 % of the variance), and between the three factors ($F(84,2436)=2.04$; $p<0.001$; explaining 0.4 % of the variance). Indeed, total annoyance response increases faster according to the sound emergence level for the ambient noises composed of the noise IN_2 and depending on the type of background noise.

### Noise contribution to total annoyance

For ambient noises composed of NA, total annoyance is lower than the specific annoyance due to the industrial noise (similar results are found for ambient noises composed of RE). For ambient noises composed of RO, when the industrial noise in the combination is more annoying than the background noise, total annoyance is close to the specific annoyance due to the industrial noise. When specific annoyance due to the separate noises is about equal, total annoyance is higher than the specific annoyance due to each noise considered in isolation. Similar results are observed for ambient noises composed of CI or BU.

Findings similar to those presented by Vos (1992) are thus highlighted for the ambient noises composed of these industrial noises and one background noise, RO, CI or BU. However, for the ambient noises composed of NA or RE, total annoyance is lower than the specific annoyance due to the industrial noise. In fact, NA and RE are composed of natural noises (brook noise and bird song) and voices. Indeed, Lavandier and Defréville (2006) observed that voices and birds increase the pleasantness of urban sound environments, and mechanical sources deteriorate the quality of the sound environment. Moreover, Nilsson et al. (2007) highlighted that soundscape quality was highly correlated with identification of technological noises (negative correlation) and identification of nature noises (positive correlation). Therefore, the background noises NA and RE seem to have a positive effect on total annoyance response.

### Assessment of total annoyance indicators

Several total annoyance models are proposed in the literature (Marquis-Favre et al. 2005), psychophysical models and perceptual models using specific annoyance of each noise in combination. Their predictive powers have been compared through several previous studies in laboratory conditions or from survey data (e.g. Berglund et al. 1981; Ronnebaum et al. 1996; Kaku et al. 1999). From these conclusions, 4 models are tested to assess their predictive power of the measured total annoyance; they are listed in the following.

The energy summation model calculates the total annoyance *A* due to *n* combined noises using $L_{s,i}$ the SPL of each noise i in combination:

$$A = f(L_T) \quad \text{with} \quad L_T = 10\log_{10}\left(\sum_{i=1}^{n} 10^{\frac{L_{s,i}}{10}}\right) \tag{1}$$

The dominance model considers that the total annoyance is equal to the maximum of the specific annoyance, $A_{s,i}$, due to each noise i:

$$A = \max_{i=1,\ldots,n}\left(A_{s,i}\right) \tag{2}$$

The energy difference model includes the global SPL, $L_T$, of the noise combination and the absolute difference between SPL, $L_{s,1}$ and $L_{s,2}$, of the two combined noises (Taylor 1982):

$$A = f_1(L_T) + f_2\left(\left|L_{s,1} - L_{s,2}\right|\right) \tag{3}$$

The weighted summation model (Vos 1992) is defined as follows:

$$L = k \times \log_{10}\left[10^{\frac{L_{s,ref}}{k}} + \sum_{i=2}^{n} 10^{\frac{L_{s,i}+P_i}{k}}\right] \quad \text{(dB(A))} \tag{4}$$
$$\text{with } P_i = \frac{\left[a_i - a_1 + (b_i - b_1) \times L_{s,i}\right]}{b_1}$$

where $L_{s,ref}$ is the SPL of the reference noise, $L_{s,i}$ the SPL of each noise $i$ in combination, $k$ a parameter set at a mean value of 15, and finally, $A_{s,ref}$ and $A_{s,i}$, the specific annoyance models due to each noise and $a_1$, $b_1$, $a_i$ and $b_i$, their regression coefficients (see Eq. (5)).

$$A_{s,ref} = a_1 + b_1 \times L_{s,ref} \quad \text{for the reference noise}$$
$$A_{s,i} = a_i + b_i \times L_{s,i} \quad \text{for the noise i} \tag{5}$$

The total annoyance is then calculated from the annoyance model of the reference noise applied to the total rating sound level $L$:

$$A = a_1 + b_1 \times L \tag{6}$$

The predictive powers of these models are compared by calculating linear regression models between the measured noise annoyance and the predicted noise annoyance. The models giving better prediction are the one with the higher correlation coefficient (see Table 1) and following normality and homoscedasticity of the residuals.

**Table 1:** Total noise annoyance models for the ambient noises studied (* statistically significant).

| Models | Background noise combined with industrial noise | Correlation coefficient r | Regression line between measured and predicted total noise annoyance | |
|---|---|---|---|---|
| | | | slope | intercept |
| The energy summation model $A$=0.38$L_T$-12.78 | NA, RE, CI, BU and RO | 0.97* | 0.94* | 0.34* |
| The dominance model | NA | 0.90* | 0.94* | 0.95* |
| | RE | 0.87* | 0.88* | 1.22* |
| | CI | 0.93* | 0.98* | -0.36 |
| | BU | 0.90* | 1.16* | -2.03* |
| | RO | 0.90* | 1.02* | -0.43 |
| The energy difference model | NA | 0.92* | 0.84* | 0.50* |
| | RE | 0.90* | 0.80* | 0.65* |
| | CI | 0.93* | 0.87* | 0.80* |
| | BU | 0.93* | 0.87* | 1.02* |
| | RO | 0.91* | 0.83* | 1.37* |

For all types of background noise, the regression coefficient associated with the difference term of the energy difference model is not statistically significant. Similar results were previously observed (Taylor 1982; Kaku et al. 1999). Compared with the energy summation model, the energy difference model does not lead to better prediction of total annoyance. For the energy summation model, a good correlation coefficient is obtained between measured and predicted noise annoyance responses but the hypothesis of the residual homoscedasticity is not respected.

The total annoyance predicted by the dominance model is overestimated or underestimated depending on the type of background noise.

From results previously presented, the use of the weighted summation model is only relevant to predict total annoyance due to the ambient noises composed of the background noises CI, BU or RO. Thus, considering all types of background noise, we propose to adapt the weighted summation model to the ambient noises studied. Firstly, the weighted summation model calculates the total rating sound level *L* (cf. Eq. (7)) considering the industrial noise as the reference noise:

$$L = k \times \log_{10}\left[10^{\frac{L_{s,ref}}{k}} + 10^{\frac{L_{s,BN}+P_{BN}}{k}}\right] \quad \text{(dB(A))}$$
$$\text{with } P_{BN} = \frac{\left[A_{s,BN} - a_1 - b_1 \times L_{s,BN}\right]}{b_1} \quad (7)$$

where $L_{s,ref}$ is the SPL of the industrial noise, $L_{s,BN}$ the SPL of the background noise, $a_1$, and $b_1$ the regression coefficients of the specific annoyance $A_{s,ref}$ of the industrial noise (Eq. (8)), $A_{s,BN}$ the specific annoyance of the background noise assessed during the listening test.

$$A_{s,ref} = a_1 + b_1 \times L_{s,ref} = -6.8 + 0.27 \times L_{Aeq} \quad \text{for the reference source} \quad (8)$$

In the weighted summation model (Vos 1992), the total annoyance *A* is calculated from the annoyance relationship of the reference noise (Eq. (8)) applied to *L* and leading to Eq. (6). In the following, this model is adapted to the studied noises.

The relationship of the annoyance due to the industrial noise with a main component in middle frequencies is composed not only of the A-weighted SPL $L_{Aeq}$, but also of the number of the spectral components *Nr* and of the $N_{(4\text{-}9Barks)}$-$N_{(2\text{-}3Barks)}$ difference (Alayrac *et al.* 2010). This relationship is given in Eq. (9):

$$A = 0.29 \times L_{Aeq} + 0.07 \times Nr - 0.21 \times (N_{4-9Barks} - N_{2-3Barks}) - 7.52 \quad (9)$$

where *Nr* is a physical index based on a detection algorithm to select spectral components (cf. (ISO 1996-2 2007) and (Pedersen *et al*. 2000)), $N_{(4\text{-}9Barks)}$ is the loudness from the critical bands 4 to 9 Barks, $N_{(2\text{-}3Barks)}$ is the loudness from the critical bands 2 to 3 Barks.

The model proposed by Vos is thus adapted with the use of Eq. (9) instead of using Eq. (6) when calculating the total annoyance A from the total rating sound level *L*. This adapted model allows the effect of identified spectral features on annoyance to be taken into account by using the number of the spectral components *Nr* and the $N_{(4\text{-}9Barks)}$-$N_{(2\text{-}3Barks)}$ difference, calculated on the whole ambient noise.

$$A = 0.29 \times L + 0.07 \times Nr - 0.21 \times (N_{4-9Barks} - N_{2-3Barks}) - 7.52 \quad (10)$$

A parameter, Δ expressed in dB(A), is also inserted to take into account the positive effect of the background noises NA and RE, composed of natural noises:

$$A = 0.29 \times (L - \Delta) + 0.07 \times Nr - 0.21 \times (N_{4-9Barks} - N_{2-3Barks}) - 7.52 \quad (11)$$

Δ is equal to 3 dB(A) for the ambient noises composed of NA and to 6 dB(A) for the ambient noises composed of RE. k is kept at 10 for all the ambient noises. Miedema (2004) used the same value for k. This adapted model allows good prediction of total annoyance for all ambient noises tested (cf. Figure 2 and Table 2).

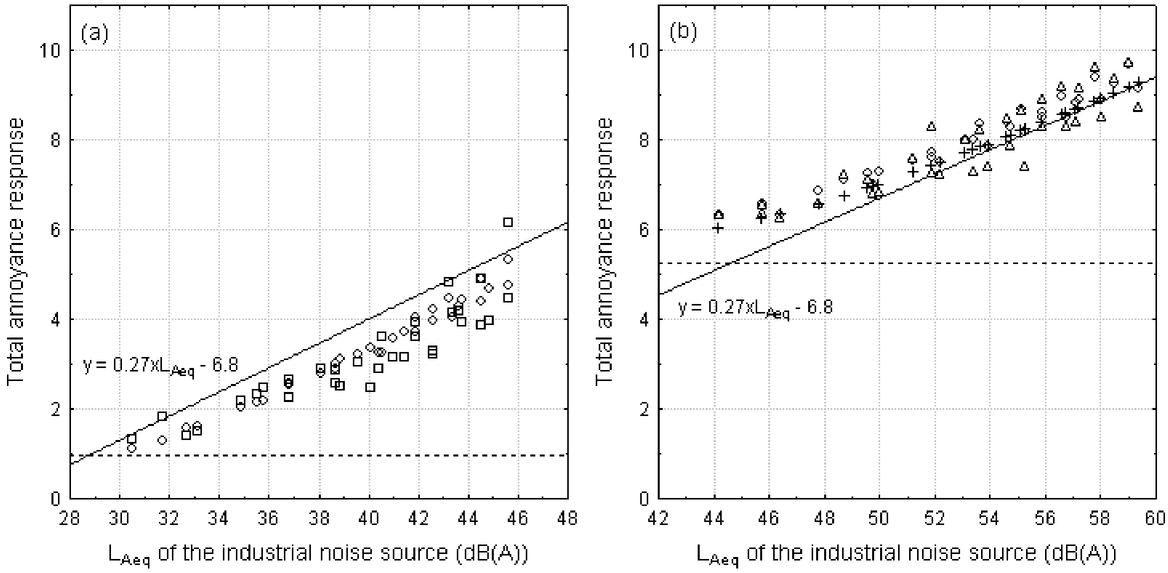


**Figure 2**: Mean total annoyance response versus A-weighted SPL of the industrial noise and depending on the background noise type. **(a)** for the background noise NA set at 37.5 dB(A); □: measured total annoyance; o: predicted total annoyance with the adapted model (k=10 and Δ=3dB(A)); **(b)** for the background noise RO set at 51 dB(A); Δ: measured total annoyance; **+**: predicted total annoyance with Vos' model (k=10); o: predicted total annoyance with the adapted model (k=10). —: specific annoyance due to industrial noise; - - -: specific annoyance due to background noise. The specific annoyance due to industrial noise is defined in (Alayrac et al. 2010).

**Table 2:** The Vos' adapted model for the ambient noises studied (* statistically significant)

| Background noise combined with industrial noise | Correlation coefficient r | Regression line between measured and predicted total annoyance, defined respectively by slope and intercept | |
|---|---|---|---|
| NA | 0.93* | 0.95* | 0.31 |
| RE | 0.92* | 0.93* | 0.28 |
| CI | 0.97* | 0.95* | 0.36 |
| BU | 0.95* | 1.1* | -0.96 |
| RO | 0.96* | 0.89* | 1.01* |

## CONCLUSIONS

Total annoyance models are tested to predict total annoyance due to ambient noises composed of one industrial noise with a main spectral component in middle frequencies and one of the five background noises tested. A model adapted from the weighted summation model is proposed. This model takes into account the effect on noise annoyance of the industrial noise spectral features through the number of spectral components *Nr* and the $N_{(4\text{-}9Barks)}$-$N_{(2\text{-}3Barks)}$ difference. Mean total annoyance response is thus better predicted for all types of ambient noises studied. This result is quite interesting, since these spectral features have been identified in the case of exposure to the industrial noise in isolation. This model has to be confronted to other combined noise situations and noise annoyance survey data.

## ACKNOWLEDGMENTS

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# The effect of regional living environmental improvement on community response to aircraft noise

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## INTRODUCTION

During the past four decades, the Japanese Government has performed any kind of measures for mitigating severe noise impact around airfields, which means civil airports and airbases of defense facilities, systematically under the national framework of airfields environmental measures. Although the aircraft noise measures of our country have introduced in the emergency when the aircraft noise exposure level was enormous, modern concept of environmental problems have changed from that of end-of-pipe to the principle of prevention. It can be said as an efficient preventive measure that making up the situation in which resident moderates community annoyance with constructing the good partnership between local community and airfields even if the people live in the high noise exposure region. As shown by Mayuzumi (2003) and Shinohara et al. (2007), the land around airport is used for creating natural ecosystem, contribution to agricultural industry, developing of a resource recycling system and so on around Narita International airport. This land use would be performed in order to promote a partnership between airport and the residential or local community as well as to prevent noise related problems from occurring.

This paper gives the results of a small size questionnaire survey around a military airfield in order to examine the effect of regional living environmental improvement on response to aircraft noise and discuss about promoting a better partnership between defense facilities and the local community or residence.

## METHOD

### Procedure

Questionnaire survey was conducted to the residents living around Atsugi airbase in 2006 using a leave-and-pick-up method. The airbase is operated by Japanese self-defense force and US force. The questionnaire was distributed to residents living in the area where the noise exposure level ranged from 70 to 90 by $WECPNL_d$. The index of $WECPNL_d$ used for Japanese airbases is denoted using an approximation of the original equation defined in the past document of ICAO Annex 16 and Japanese original index, where, $WECPNL_d$ is nearly equal to $L_{den}$ + 18 dB. In this paper, $L_{den}$ is used for the index of noise exposure level.

### Questionnaire

Questionnaires included the five items questions which were 1) evaluation of quality of life such as convenience of life, total living environment, degree of satisfaction with work, recreation and so on, 2) evaluation of living environment such as local air quality, sound environment, urban ecosystem and local water quality, 3) evaluation of annoyance of aircraft noise, 4) degree of satisfaction with measure for regional living environmental improvement such as improvement of urban ecosystem or construction of public facilities and 5) face sheet. 5-point verbal annoyance scale (“extremely”, “very”, “moderately”, “slightly” and “not at all”) was used in the questionnaire of item 3.

## Respondents

Table 1 shows the sample size and valid responses of this survey. The questionnaire was distributed to 144, 197, 467 and 394 residents living in the areas where $L_{den}$ is less than 57, ranged from 57 to 62, from 62 to 67 and more than 67 respectively. The total sample size of this study was 1202. As a result of the survey, 362 responses were obtained from the areas (response rate 30.1 %). Table 2 shows gender and age of the valid respondents.

**Table 1:** *T*he sample size and valid responses of this survey

| $L_{den}$ | Valid responses | Distribution | Valid response rate |
|---|---|---|---|
| -57 | 90 | 394 | 23 % |
| 57-62 | 118 | 467 | 25 % |
| 62-67 | 41 | 197 | 21 % |
| 67- | 31 | 144 | 22 % |

**Table 2:** Gender and age of the valid respondents

| Age | Male | Female | Total |
|---|---|---|---|
| 20-29 | 3 | 2 | 5 |
| 30-39 | 4 | 13 | 17 |
| 40-49 | 12 | 23 | 35 |
| 50-59 | 39 | 24 | 63 |
| 60-69 | 70 | 30 | 100 |
| 70- | 54 | 6 | 60 |
| Total | 182 | 98 | 280 |

# RESULTS

## Dose-response relationship between %HA and $L_{den}$

Using data of item 3 in the questionnaire, dose-response relationship between $L_{den}$ and highly annoyed response rates was calculated and shown in Figure 1. The number of people who responded to only top category of 5-point verbal scale was counted as percent highly annoyed (%HA). X-axis means $L_{den}$, Y-axis means scale value of annoyance. Bar scale means 95% confidence interval. Jonckheere-Terpstra trend test was taken and it was confirmed that %HA significantly increased according to $L_{den}$.

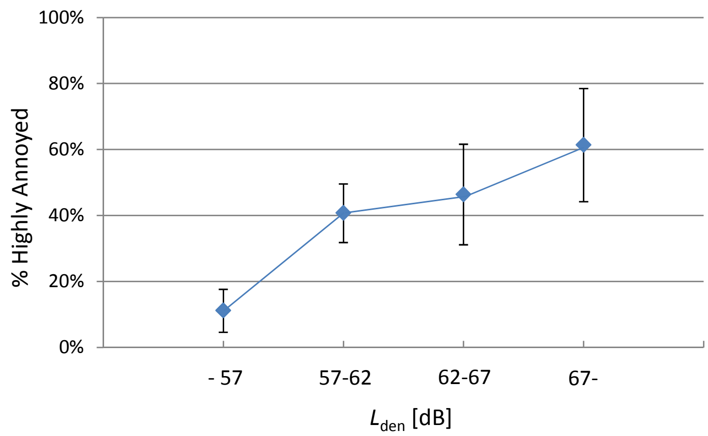


**Figure 1:** Dose-response relationship between $L_{den}$ and %HA (Bar scale means 95% confidence interval of %HA for each $L_{den}$ category)

### Degree of satisfaction with measure for regional living environmental improvement

Using data of item 4 in the questionnaire, the relation between degree of satisfaction with measure for regional living environmental improvement and $L_{den}$ was examined. The evaluation of the satisfaction on verbal scale ("satisfy", "not satisfy" and "neither") were dichotomized by categorizing as "satisfy" response and "not satisfy or neither" response. Multiple logistic regression analysis was applied to the rate of "satisfy" response. The categories of $L_{den}$ (less than 57, 57-62, 62-67 and more than 67 dB) were included in the logistic model as independent variables. In order to adjust for confounding factors, gender (male, female), age (20-39, 40-59, and elder than 60) and residence year (less than 1 year, 1-3 years, 3-10 years, and more than 10 years) were also included in the model as independent variables.

Figure 2 shows the result for the logistic regression analysis. The control of the odds ratio was the value at the site of "less than 57 dB". The asterisk indicates significant odds ratios (*: $p$<0.05, **: $p$<0.01).

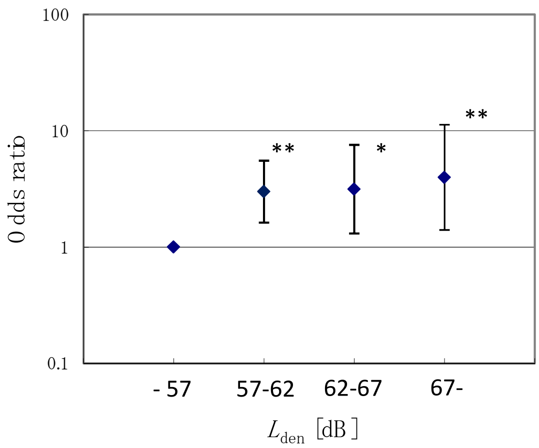


**Figure 2:** Odds ratio of satisfaction with measure for living environment improvement vs. $L_{den}$ (Bar scale means 95% confidence interval of odds ratio for each $L_{den}$ category)

This result suggests that residents living in the area where aircraft noise level is moderately high are not satisfied with measure for living environment improvement now, and there is some kind of inter-linkage between satisfaction with the measure and annoyance.

**Effect of regional living environmental improvement on community response**

Figure 3 shows two kinds of dose-response relationships, one is calculated using response of annoyance whose respondent satisfied with the environmental improvement around airbase such as developing parks, and the other is calculated using response rate of annoyance whose respondent doesn't satisfy with. X-axis means $L_{den}$, Y-axis means scale value of annoyance. Bar scale means 95% confidence interval. It is found that the feeling of annoyance is mitigated by satisfying with environmental improvement in the area where $L_{den}$ is less than 62 dB. This result suggests the possibility that defense facilities and the local community or residence can promote a better partnership if the land-use or environmental improvement is accepted by residence after aircraft noise exposure level is decreased on a some level. At the same time, the feeling of satisfaction with environmental improvement doesn't contribute to mitigating annoyance in the region where noise exposure level is higher, and this result also supports the concept of traditional aircraft noise measure that noise reduction at source should be done firstly in the area where aircraft noise exposure level is enormous.

Figure 4 shows the ideal measure for living environmental improvement that respondents answered in the questionnaire item 4. Many of them answered that urban ecosystem is needed. Urban eco system might assume an important role for promoting a better partnership between defense facilities and the local community or residence.

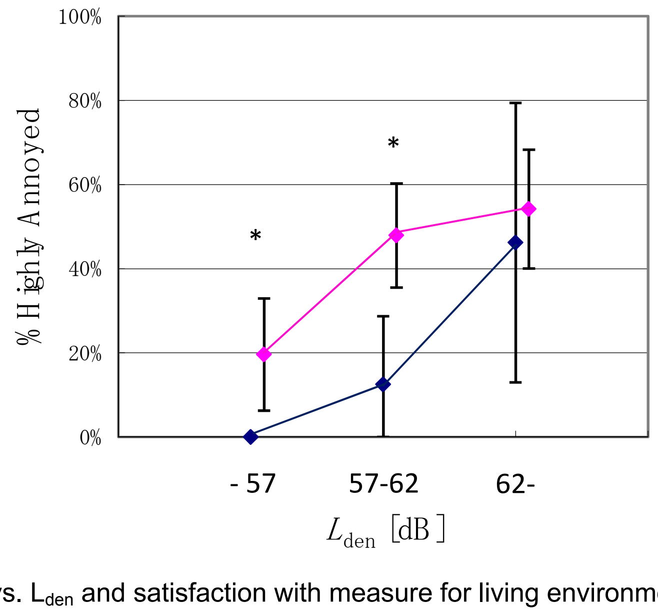


**Figure 3:** %HA vs. $L_{den}$ and satisfaction with measure for living environmental improvement (Bar scale means 95% confidence interval of %HA for each $L_{den}$ category)

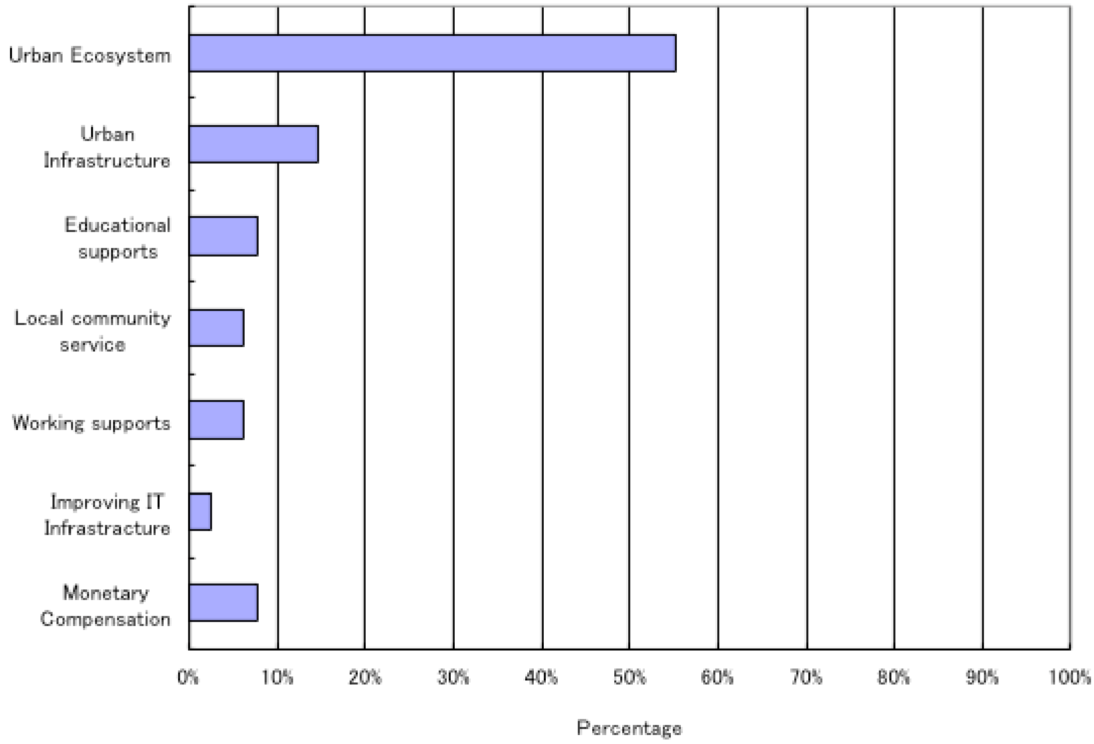


**Figure 4:** The ideal measure for living environmental improvement that respondents answered

## CONCLUSION

This paper gives the results of a questionnaire survey around a military airfield and it was found as below.

- Residents living in the area where aircraft noise level is moderately high are not satisfied with measure for living environment improvement, and there is some kind of inter-linkage between satisfaction with the measure and annoyance.
- It would be suggested that the possibility that defense facilities and the local community or residence can promote a better partnership if the land-use or environmental improvement is accepted by residence after aircraft noise exposure level is decreased on a some level.
- The feeling of satisfaction with environmental improvement doesn't contribute to mitigating annoyance in the region where the amount of the noise exposure is higher.
- Urban eco system might play an important role for promoting a better partnership between defense facilities and the local community or residence.

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# Issues in the development of a survey simulation tool to explore robust estimation of models of annoyance due to aircraft noise

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## ABSTRACT

A community survey simulation tool is described that has been developed to examine the effects of sampling populations around airports on the estimation of annoyance models. Aircraft noise exposure is predicted on a fine grid around airports for single operations with Integrated Noise Model (INM) or Noise Model Simulation (NMSim); these are used with airport operations scenarios to determine noise exposure at points on a finely resolved grid. Survey populations are defined for the areas surrounding the airports using available microdata and aggregate data from the U.S. Census; households and associated individuals are assigned to noise grid points. Demographic data can be incorporated into the simulation tool to examine the potential for non-acoustic confounding factors. Various sampling methodologies and signal-to-noise ratios are used in Monte Carlo simulations to examine how they affect parameter estimates in an annoyance model that includes number-of-events and a measure of average event sound level as predictor variables.

## INTRODUCTION

A goal of current research is to predict how a community will react to changes in airport operations. Advances in aircraft design are resulting in reductions in sound level produced by aircraft, but aviation forecasts predict continuing growth in air traffic in the years to come. A central question surrounding the topic of annoyance to aircraft noise concerns a trade-off between the number-of-events and the sound level of aircraft. Most predictive models of community annoyance to aircraft noise are functions of the average A-weighted sound energy and do not explicitly contain an independent number-of-events term. Different combinations of aircraft sound levels and number-of-events can produce the same A-weighted energy average, but do they result in the same level of community annoyance?

Several researchers have developed models that are an alternative to energy equivalence-based models such as $L_{dn}$, $L_{den}$, or $L_{night}$. These alternative models typically contain two types of terms: measures of the sound level of events, e.g., average of individual events' $PNL_{max}$, $L_{Amax}$, *ASEL,* etc.; and number-of-events (*N*) above a certain sound level (Rylander et al. 1980), or the logarithm of the number-of-events above a certain sound level (TRACOR 1970, 1971; Connor & Patterson 1972, 1976; Rice 1977a, b; Powell 1980; Bullen & Hede 1986a, b; Vogt 2005; Le Masurier et al. 2007). The noise exposure forecast (*NEF*), Australian variant (*ANEF*), and Noise and Number Index (*NNI*) are community noise metrics that also involve number-of-events terms, see, e.g., Bradley (1996). While such measures are used in some countries, other countries have moved to using metrics based on average A-weighted sound energy. In the ANASE study in the UK (Le Masurier et al. 2007) there was an argument made for including a number-of-events term based on a comparison of the data collected in that study to data collected earlier in the Aircraft Noise Index Study (Brooker et al. 1985), though there is some disagreement as to whether the data supported that conclusion (Brooker 2008a, b).

In an analysis of older community survey data, Fields (1984) examined the ratio of the estimated coefficients for the two types of terms (logged number-of-events over sound level) for different field studies; the ratios varied considerably from study to study, ranging from -3.7 to 23.8. Some of this variation can be attributed to different ranges of variables within particular studies and the use of different sound level metrics, as well as difference in the instrument used to measure annoyance, but even taking this into consideration, there does not seem to be a great deal of consistency between the estimated models from different field studies.

Community surveys have been the tool of choice in the formation of annoyance models but are also the validation tool for models proposed from the results of laboratory-based studies. However, there are challenges in estimating parameters in models containing both number-of-events and sound level terms from survey data. The number-of-events heard and the average sound level of events are often correlated because when events are louder, more are heard. If a number-of-events term is added to an energy-based term in a model, then, unless the mix of aircraft is changed at an airport, an increase in the number-of-events will lead to an increase in average sound level. As the degree of correlation between the variables changes (as it will from study to study) then the model parameter estimates will also vary. When, for a sample population, there is partial correlation between variables used in the model, it is impossible to separate out each variable's individual contribution to the output (annoyance). A more extreme form of this problem is called multicollinearity; this is when there is a high degree of correlation between variables (columns in the data matrix used for the estimation are close to being linearly related). This is a well-known problem in the estimation of regression models, see, e.g., Belsley (1991). The result is an ill-conditioned data matrix so that estimation results are very sensitive to perturbations in the data matrix. In addition, the variance of the estimates increases as the data matrix becomes more ill-conditioned. This is relevant because the variables are measured or predicted and thus, a certain level of uncertainty will be present in the data matrix.

The simulation tool has been developed to help determine if it is possible to sample a population around an airport in a manner that minimizes collinearity in the data matrix that is used to estimate annoyance model coefficients. The focus of the investigation reported here is on collinearity between acoustical variables, but demographic information is incorporated into the simulation tool obtained from US Census data (US Census Bureau 2000). Health data could also be incorporated in the future by using CDC data (CDC 2011).

## SURVEY SIMULATION APPROACH

There are many possibilities in sample design, but the main focus of this work was to study the effect of stratification. The essence of stratification is the classification of a survey population into groups, or strata, based on available information about the population. Samples are then further selected from each of the strata. In practice, strata can be formed by using any available information about a population, both acoustical and non-acoustical. Only acoustical variables were explored as stratification variables in this work, but correlations between acoustical and non-acoustical variables in the population were examined.

The simulation tool was designed with the intent of representing possibilities at existing airports. Thus, it was required to select particular airports and associated communities on which to base the survey simulations. Here results from only one airport are given, but the approach would be the same for each airport included in a survey. Possibilities for future work include exploring whether including multiple airports in a single survey can be helpful in controlling collinearity. A description of the methodology applied in a survey simulation follows.

### Acoustical environment specification

The Integrated Noise Model (INM) or Noise Model Simulation (NMSim) is used to generate acoustical output of single operations on a grid of points spaced at 0.1 nautical miles (nm). The grid of points is centred on the airport and extends outward in each cardinal direction (for the specific airport used as an example in this paper, the grid extended 10 nm outward). An "operation" is defined as one arrival or departure of a single aircraft operating at a certain flight profile on one flight path. Based on actual known airport operations, a realistic annual operations scenario is specified and used in conjunction with the stored acoustical output to generate sound level metrics at each location on the grid.

### Demographic specification

U.S. Census 2000 data is used to specify the demographics of the population surrounding the airport. Both aggregate-level tabulations, reported in Summary File 3 (SF3) and 5 % public use microdata sample (PUMS) files are used in the demographic specification. The 5 % PUMS data are computerized versions of the census questionnaires, as coded and edited during census processing.

Combinatorial optimization (Huang & Williamson 2001; Ryan et al. 2009) is used to design the demographics of the population surrounding the airport; it is a method of selecting microdata records that best fit the aggregate-level tabulations for each census block given in SF3. A population is generated for the census block groups of the county containing the selected airport from microdata belonging to a larger geographical region that encompasses the airport.

### Geographic specification of potential survey participants

Each grid point used in the acoustical environment specification has associated latitude and longitude. U.S. Census 2000 TIGER/Line shapefile data, or polygonal shape data, for the census block groups of the county containing the airport are collected. From an analysis of the spatial data, each of the grid points is associated with a census block group. The number of households in each census block group is compared with the number of acoustical grid points within it. Linear interpolation of the acoustical data grid is performed so that the number of acoustical grid points is larger than the number of households in each census block group. In each census block group, households (and associated individuals) are randomly assigned to acoustical grid points. Note that sound level metrics are converted to "mean square pressure or equivalent" before interpolation.

### Annoyance specification

An average state of annoyance is defined for the population. In the example given in this paper, the average annoyance ($A$) due to aircraft noise at each grid point was specified using:

$$A = 0.069\ PNL_{max,av} + 0.22\ log_{10}(N) - 4.278, \quad (1)$$

where $PNL_{max,av}$ is a logarithmic average of the Perceived Noise Level (*PNL*) of events above a threshold of 80 dB, and *N* is the annual number of events above that threshold. This is a model derived from a reanalysis of older aircraft noise survey data. Shown in Figure 1 is an annoyance map generated using Equation (1) for a particular flight operations scenario. Also shown on this map are the *Ldn* contours.

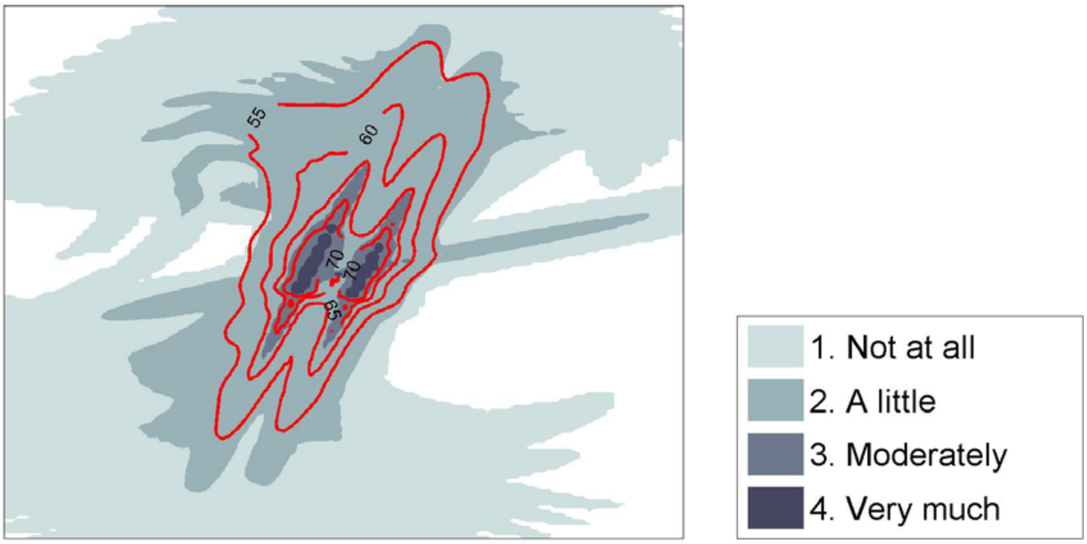


**Figure 1:** Annoyance contours developed using a model derived from a reanalysis of older survey data (Equation (1)). Also shown in red are the *Ldn* 55, 60, 65 and 70 dBA contours. This is based on an operations scenario that included 113,930 flights per year, random variation of 89 different flight tracks and 15 different aircraft.

## SPECIFICATIONS FOR SIMULATIONS AND ANALYSIS

Scenarios for Monte Carlo simulation are created through combinations of values of different specification variables, those being the signal-to-noise ratio ($R^2$), or fraction of output variance attributable to the annoyance relationship in the population, the size (*n*) of the sample drawn from the total population for a noise survey, and the number of strata in classifying the population prior to sampling.

$R^2$ is controlled through varying the annoyance assigned to households from the model. For each household, annoyance values are assigned based on an assumption that annoyance scores would be distributed about the average value predicted from Equation (1), the variation being due to the many unmeasured things that affect responses at the time of filling in a questionnaire. The actual annoyance assigned to a grid point was thus: $A + na$ where $na$ is a zero mean uniformly distributed random variable with the required variance: $var(na) = var(A)(1\text{-}R^2)/R^2$.

Choosing a single sample involves randomly selecting a household within a stratum, and then randomly selecting an adult (person at or above 18 years of age) residing in that household. Once a household is chosen, it is excluded from consideration, so that repeats are avoided. Thus, stratified random sampling without replacement, or simple random sampling without replacement (for the case of no stratification) is used to sample the population of grid points. Strata boundaries are determined so that each stratum contains a number of population households no less than two times the sample size used for a noise survey divided by the number of strata. If this is not possible for certain cases, the criterion is relaxed.

For each designed scenario, Monte Carlo simulation is used in which a noise survey is simulated for a pre-set number of trials. For each trial, or noise survey, acoustical variables of a model hypothesized to have generated the population annoyance, and the annoyance response generated as described above, are recorded for each of the sampled individuals. For the simulations used in this investigation the hypothesized model is the same as the simulated model. Non-acoustical variables describing population characteristics can also be recorded. For the simulations reported here, two socio-economic variables were recorded: the total household income and the age of the sampled individual. For each trial, two regressions were performed; these are referred to as "standard" (acoustical variables only) and "augmented" (acoustical and non-acoustical variables).

For the investigation simulations, levels of the specification variables were defined as follows. The values of $R^2$ chosen were 0.05, 0.20, and 0.40. Sample sizes for the simulated surveys were set at 500, 2,000, and 4,000. Four different levels of stratification were specified. Each predictor variable in the model of annoyance, $PNL_{max,av}$ and $N$, was divided into 2, 3, 4, or 5 groups each so that 4, 9, 16, and 25 strata, respectively, were realized. The case of no stratification was also investigated, yielding 5 total levels of stratification. Thus, through combinations of the 3 levels of $R^2$, 3 sample sizes, and 5 levels of stratification, a total of 45 scenarios for simulation were realized. 100 Monte Carlo trials were used for each survey simulation.

## RESULTS OF FITTING MODELS TO THE ANNOYANCE "SURVEY" DATA

The parameter estimates from the 100 trials were analyzed and the biases and standard deviations for each of the parameter estimates were estimated. For the intercept and the coefficients of the acoustical variables the Type II (false negative) error rates were recorded (based on estimated 95% confidence intervals in each trial). For the socio-economic variables, which were not parameters in the simulated model, the Type I (false positive) error rates for each coefficient were calculated from the 100 augmented regression results. Also, for each trial of each simulation, the joint significance of the addition of the socio-economic variables to the standard model was assessed by calculating the marginal reduction in error sum of squares they provided. Aggregating the results over the trials for each simulation yielded an overall rate of significance (fraction of times the socio-economic variables were deemed significant contributors to the prediction of annoyance).

In the augmented models, the Type I error rates (false positives) observed for the socio-economic variables (income and age) ranged between 0.00 and 0.05, and the rates of joint significance for these variables ranged between 0.00 and 0.10. There were not significant trends for either the Type I error rates or joint significance rates with $R^2$, sample size, or stratification. Type II error rates (false negatives) for the acoustical variables in the standard model are shown in Figure 2. Slightly larger rates were found for the acoustical variables in the augmented regressions (not shown) but trends were very similar for both regressions.

A multicollinearity analysis was performed by using techniques outlined in Belsley (1991). The condition number of the data matrix in each trial of each simulation was calculated. The mean of the condition numbers for each 100-trial Monte Carlo simulation, along with percentile ranges, are shown in Figure 3. The mean of the 100 parameter estimates from each simulation and the corresponding standard deviations of the estimates, both normalized by their true values (see Equation (1)) are shown in Figure 4.

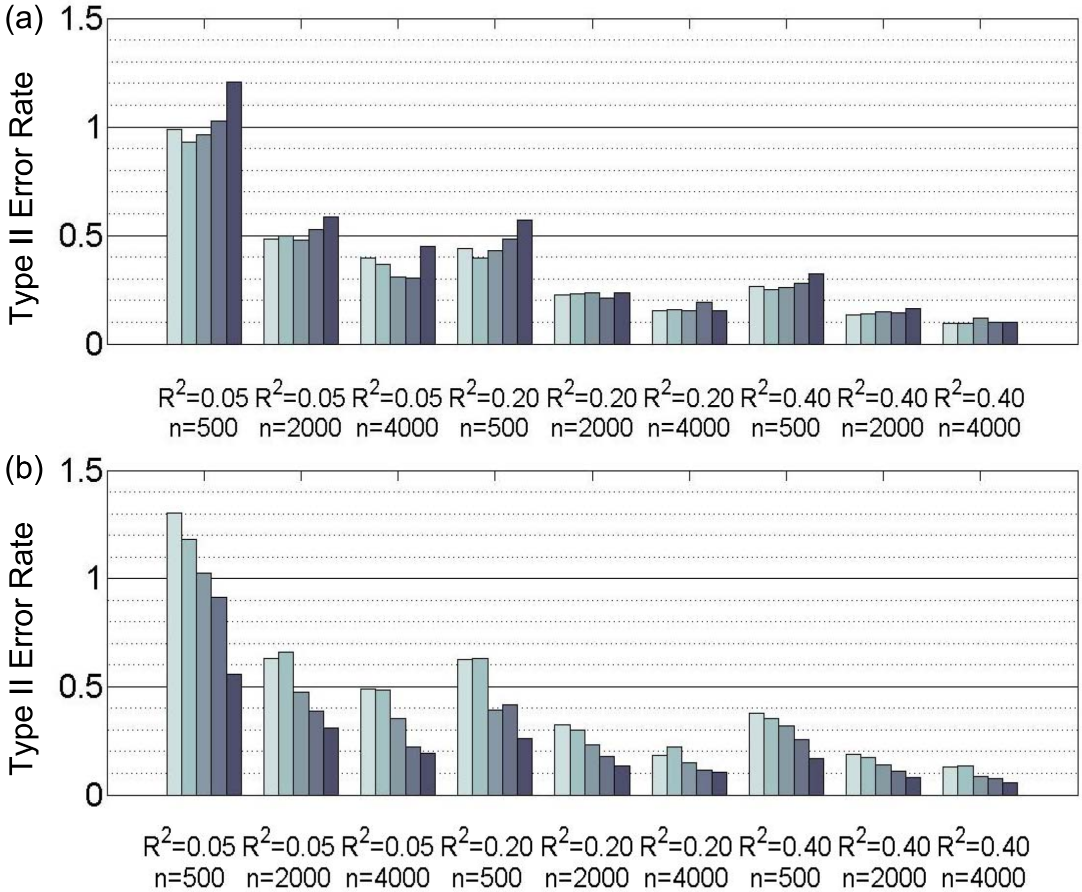


**Figure 2:** Type II error rates (false negatives) for the (a) number-of-events and (b) sound level terms from the standard regression fits. Shading (light to dark) indicates level of stratification (1, 4, 9, 16, 25 strata). Results from 100 trials in each simulation

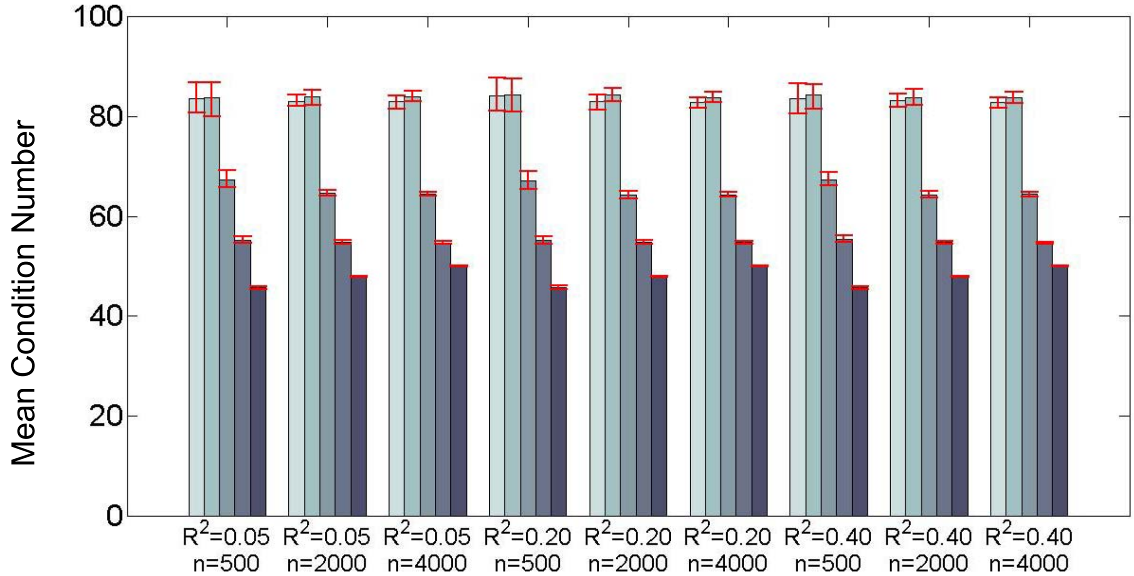


**Figure 3:** Mean condition number of data matrices for the 45 sets of Monte Carlo simulations organized as in Figure 2. Bars indicate the 25 % and 75 % percentiles.

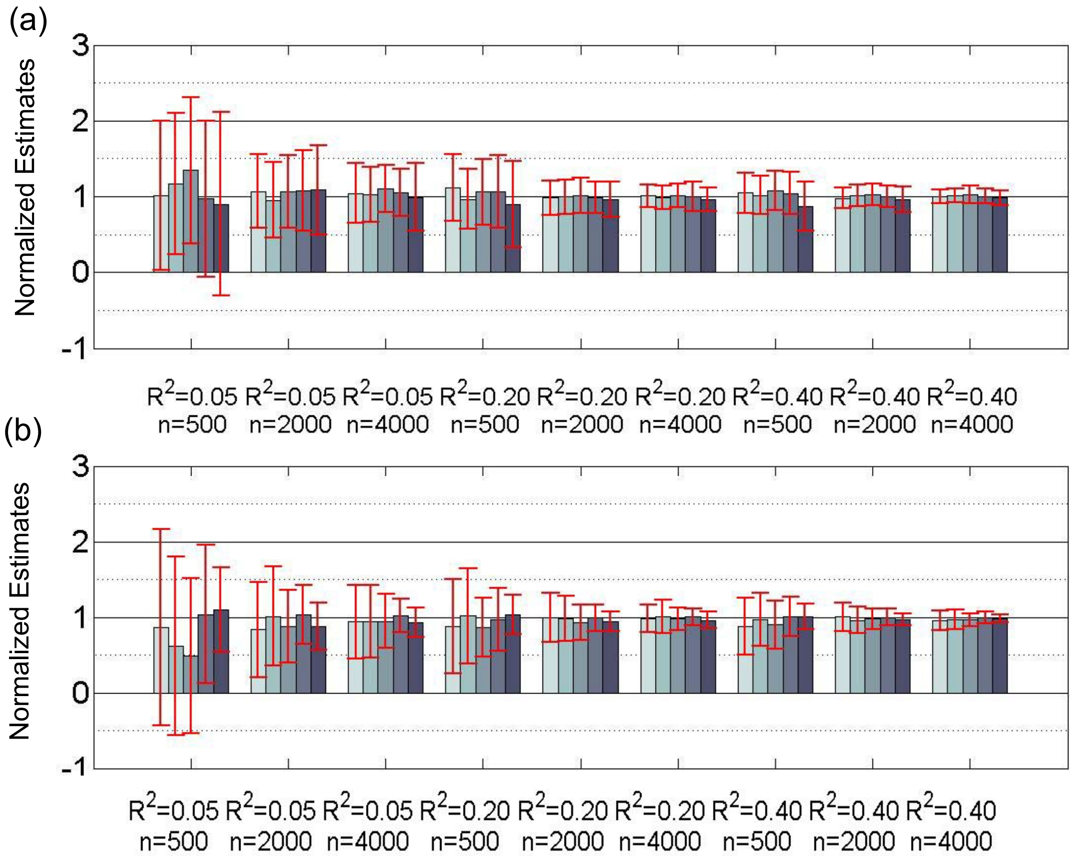


**Figure 4:** Parameter estimates and the standard deviation of the estimates from the 100 trials of each simulation, both normalized by the true values of the parameters: (a) the number-of-events coefficient (b) the sound level coefficient

Not surprisingly, simulations with smaller $R^2$ and smaller sample sizes resulted in higher standard deviation estimates. For the intercept and sound level term, increasing stratification resulted in a decrease in the standard deviation of the estimates and fewer Type II errors. For the number-of-events term, increased levels of stratification yielded little or no benefit and sometimes degraded the results. The conditioning of the data matrix improved with stratification.

## SUMMARY

A methodology to simulate noise annoyance surveys around airports was described. It includes quantification of noise exposure by utilizing sound prediction software like INM or NMSim together with aircraft operations data from the airports. Socio-economic data is included in the simulation based on data from the U.S. Census Bureau. As an illustration, the simulation tool was used to conduct a series of Monte Carlo simulations to study the effects of stratification on the estimation of parameters in a linear regression annoyance model with sound level and number-of-events terms. Stratification was found to be beneficial (reduced variance) in the estimation of the coefficient of the sound level term, even at highest signal-to-noise ratio ($R^2$) and with the largest population sample ($n$). However, stratification was not generally found to be beneficial for the estimation of the coefficient of the number-of-events term ($log_{10}(N)$). This is surprising and warrants further investigation.

## ACKNOWLEDGEMENTS

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# Mitigation of noise in nursery school classrooms by sound absorption: a yearly noise measurement with different absorbing conditions in actual classrooms

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## INTRODUCTION

Acoustic environment in nursery schools have been less discussed than those in elementary schools or junior high schools, and, in Japan, there are no standards or guidelines at present for acoustic planning of pre-school classrooms. There are several studies, however, indicating that the acoustic environment in nursery schools can be harmful to physical and mental health of children and teachers. Waye et al. (2010) reported that the average individual exposure level of children was 84 dB ($L_{Aeq}$) during the active time period in the play hall or kitchen. Grebennikov (2006) pointed out that teachers' exposure level were up to 85 dB ($L_{Aeq}$) during the six-hour work time. For the mitigation of these noisy situations of the indoor acoustic environment, sound absorption is considered to be a possible solution, and the present study aims to examine this effect. For this purpose, in the previous study (Kawai 2010), we carried out a field experiment in which sound absorbing boards were installed in the classrooms of an actual nursery school, and found the possibility of the effectiveness of sound absorption. In this study, we conducted the second experiment to ensure the evidence with more comparable condition settings.

## EXPERIMENT

### Installation of sound absorbing boards

A field experiment was carried out in the same nursery school as in the previous study (Kawai 2010) in Kumamoto city, Japan. The school takes care of six classes with children from 0 to 5 years old in the separated nursery room respectively for each year of age. Three different absorbing conditions were set to the six rooms by hanging sound absorbing boards, made of polyester fiber, on the ceilings of the classrooms using nylon strings (Figure 1). Three different absorbing area, namely about 0 (NONE), 40 (HALF) and 80 % (FULL) of the ceiling area, were assigned for each of the six rooms. The experiment period was almost a year from April 2010 to March 2011, as the academic year in Japan begins in April. The whole year was divided into three periods of 2010.4-7, 9-11, 12-2011.3 (August was omitted from this experiment because it was a special period in the school when the classes of from three to five years age were mixed). The classrooms were divided into two groups of the rooms of 0, 2 and 4 year children (R0, R2 and R4) and those of 1, 3 and 5 year children (R1, R3 and R5). In the former group, sound absorption was decreased from FULL to NONE (*Decreasing group*), and that was increased from NONE to FULL in the latter group (*Increasing group*) by each of the periods.

The original surface materials of the classrooms were not apparently sound absorptive with wooden flooring (floor), wooden or gypsum boards (partition wall), glass windows with wooden or aluminum sashes, and gypsum boards (ceiling).


**Figure 1**: Installation of sound absorbing boards

## Acoustic measurement

To obtain the acoustical characteristics of the rooms, impulse responses were measured for each of the rooms using the maximum length sequence (MLS) signals. MLS signals were produced by an omni-directional speaker, received at four points per room, and processed into impulse responses. Reverberation time and RASTI were then calculated from the impulse responses of each of the rooms.

## Noise measurement

Indoor sound was recorded in the six rooms to measure the noise levels. Since the sound levels could be affected by the distance between a microphone and sound sources (children), two microphones, both hung 30 cm below the ceiling with several meters apart from each other, were used for recording the sound simultaneously (Figure 2). In order to minimize the effect of the distance-dependent energy of direct sounds from the children, simultaneous sound pressure levels were calculated every 100 millisecond of the two recorded sound sequences and the lower value at every

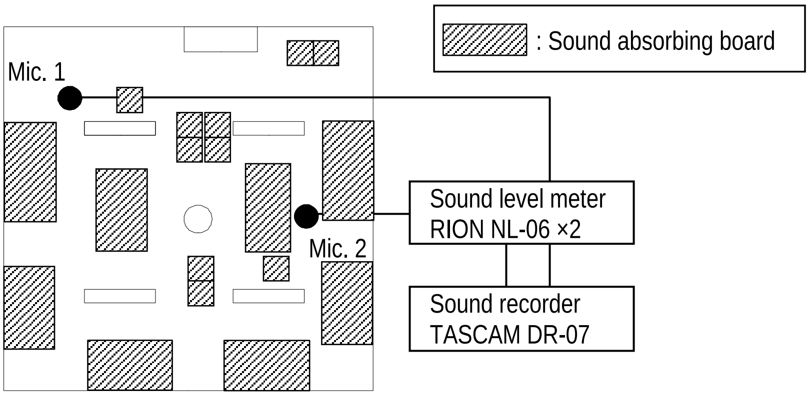


**Figure 2:** Arrangement of measuring instruments (Ceiling plan example)

**Table 1:** Dimension and absorbing conditions of classrooms

| Room | N of children | Age | W×D×H | V($m^3$) | S($m^2$) | Absorbing condition in each period (month) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Period 1 (4-7) | Period 2 (9-11) | Period 3 (12-3) |
| R5 | 21 | 5 | 6.0×7.5×3.0 | 137 | 173 | NONE | HALF | FULL |
| R4 | 20 | 4 | 6.2×7.5×3.0 | 141 | 176 | FULL | HALF | NONE |
| R3 | 22 | 3 | 6.5×6.6×2.4 | 102 | 148 | NONE | HALF | FULL |
| R2 | 25 | 2 | 6.6×6.5×2.4 | 102 | 148 | FULL | HALF | NONE |
| R1 | 16 | 1 | 5.6×6.6×2.7 | 99 | 139 | NONE | HALF | FULL |
| R0 | 13 | 0 | 5.5×6.6×2.7 | 97 | 137 | FULL | HALF | NONE |

moment was chosen. These lower values can be regarded as the sound levels of far from the sound sources and thus can be regard as the levels that represent the energy of diffused sounds rather than that of direct sounds. This also means that the measured SPL is not the exposure level for teachers or children and the values would be considerably lower than the actual exposure levels, as the purpose of this measurement is not to measure the exposure levels but to examine the effect of sound absorption.

Recordings were done for eight hours (9:00-17:00) per day. In the first period, the recordings were done on two or three days just before the condition had changed for the second period, and in the following two periods, the recordings were done once in two week basis. It is needed to select the representative time periods for the analysis of noise level because the levels in classrooms widely varied depending on the children's activity. Thus, three time period were selected: lunch time that was one of the periods in a day when children's voice was loudest, reading time in which the teacher reads a book to the children, and napping time as back ground noises.

## RESULTS AND DISCUSSION

### Acoustic characteristics

Figure 3 shows an example of the frequency characteristics of children's and teacher's voices recorded in three of the rooms. The children's voices in playing time had its main power in 1 kHz–2 kHz frequency band, and the sound pressure level was higher than teacher's voice. The frequency range of teacher's voice was lower than that of the children with its power mainly in 250 Hz–1 kHz band.

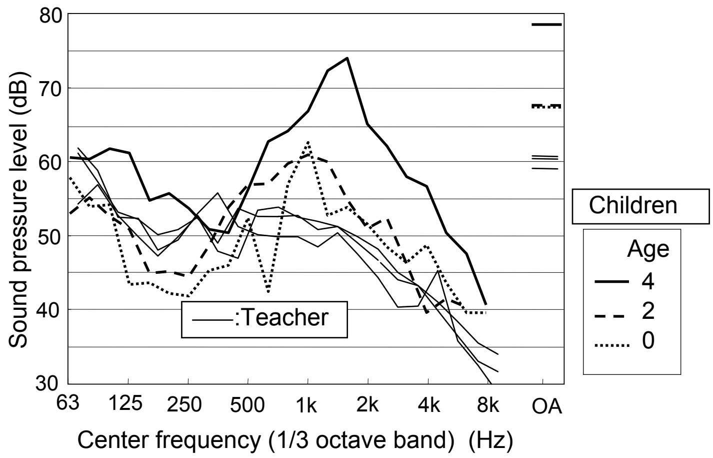


**Figure 3:** Frequency characteristics of children's and teacher's voices

Figure 4 shows reverberation time (RT) of the rooms with each absorbing conditions. The RT of 1 kHz band without sound absorbing board varied from 0.56 to 0.75 s depending on the rooms that have different ceiling heights and floor areas. Most of these RTs are regarded as too long compared to the recommended value (0.6 s) of WHO environmental noise guideline for the speech intelligibility in classrooms of elementary school and kindergarten (WHO 1999). With the installation of the absorbing boards at 40 % cover ratio (HALF), the RTs of 1 kHz band decreased to 0.39 - 0.42 s, and at 80 % cover ratio (FULL), those were 0.33-0.40 s. RASTI values calculated from the impulse responses were around 0.72 (good) and 0.84 (excellent) before and after the installation, respectively. Average absorption coefficients was then estimated from the RTs using Eyring's formula, and those with 0, 40, and 80 % cover ratio was around 0.16, 0.26, and 0.28 s, respectively, in 1 kHz band in all the rooms.

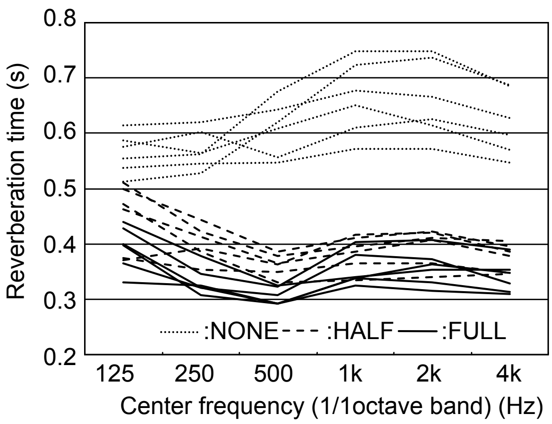


**Figure 4:** Reverberation time of the rooms with three absorbing conditions

### Sound pressure level

The daily sound pressure levels (SPL) measured in the lunch time are shown in Figure 5 and Figure 7. The levels were largely fluctuated but the trend of the noise level was seen generally as in accordance with the increase / decrease of sound absorption. Then the daily noise levels are averaged by each of the absorbing conditions (Figures 6 and 8). In the figure, it is obviously seen that the sound absorption correlated the decrease of noise level.

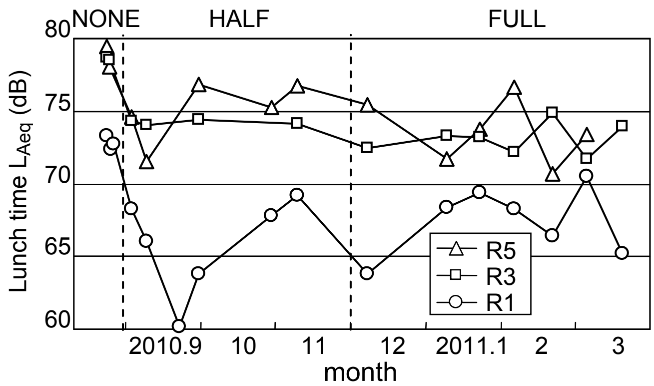


**Figure 5:** Daily noise level in lunch time (Increasing group)

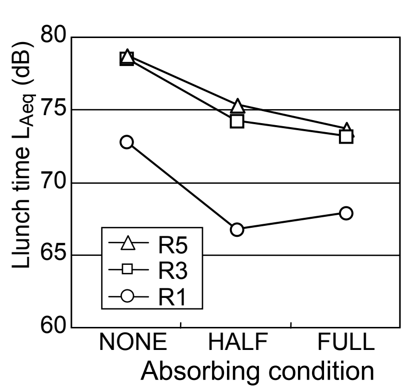


**Figure 6:** Lunch time noise level averaged by absorbing conditions (Increasing group)

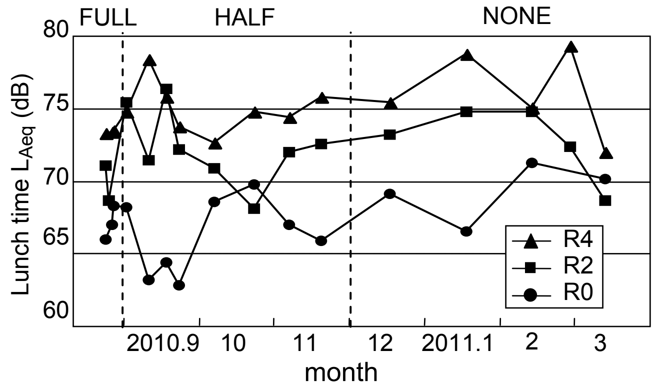


**Figure 7:** Daily noise level in lunch time (Decreasing group)

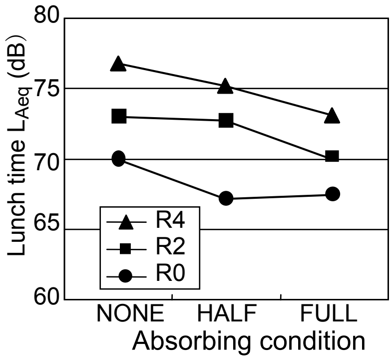


**Figure 8:** Lunch time noise level averaged by absorbing conditions (Decreasing group)

The average level differences between the conditions of NONE and FULL were 3-6 dB. This difference is greater than the expected physical level reduction by the sound absorbing power (approximately 3 dB assuming diffused sound field) and, therefore, the result suggested that the difference was affected by not only physical reduction but also by the lowered voice levels of the children possibly due to the improved speech intelligibility of the rooms by the sound absorption. The change in dB with the change of absorbing condition was different between *increasing* and *decreasing* groups. When the sound absorption increased NONE to HALF, the level decreased instantly by three to five dB while the change was not so instantly nor obvious when the condition changed from HALF to NONE. A possible reason would be that once the teacher and children were accustomed to less noisy condition created by the sound absorption, they would be accustomed not to make their voices too loud. More evidences are required, however, to ensure these additional effects and it should be obtained though observing the voice levels in further studies.

The reading times $L_{Aeq}$ are shown in Figures 9-12. The levels were even more fluctuated than the children's voice levels in lunch time probably due to the types of books read in the day. Nevertheless, they still showed the change in accordance with the condition of the sound absorption and the averaged level differences between with and without sound absorption were even greater than those in lunch time. We also asked the teachers an open question about the subjective evaluation of the room

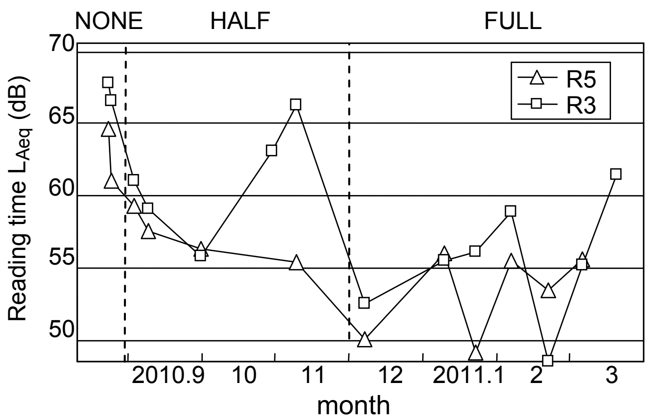


**Figure 9**: Daily noise level in lunch time (Increasing group)

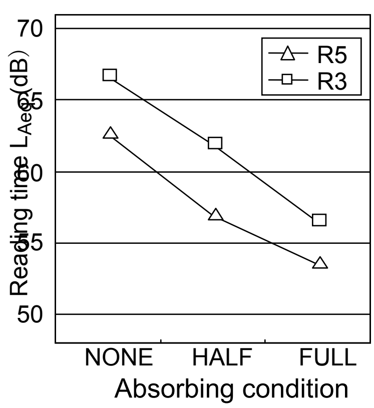


**Figure 10**: Lunch time Noise level averaged by absorbing conditions (Increasing group)

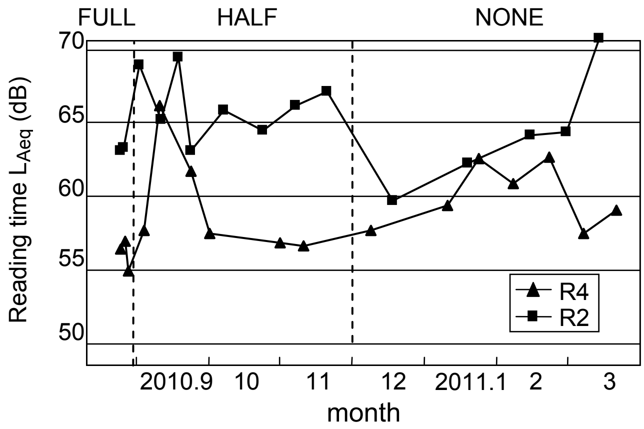


**Figure 11:** Daily noise level in reading time (Decreasing group)

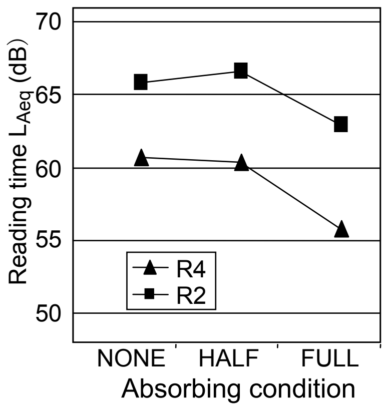


**Figure 12:** Reading time noise level averaged by absorbing conditions (Decreasing group)

with the sound absorption and found that 9 out of 18 teachers evaluated the sound absorption positively.

## CONCLUSIONS

In this study, the effect of sound absorption on the moderation of the noisy acoustic environment of nursery school classrooms was examined through a field study conducted for a year. The result supported the existence of moderating effect of sound absorption on noisy acoustic environment in nursery school classrooms. Further studies are required for accumulating more evidences, in which the exposure level and voice level, activity of children and teachers should be examined.

## ACKNOWLEDGEMENTS

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# Sound annoyance as loss of options for viability self-regulation

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## INTRODUCTION

Sound annoyance is still ill-defined as scientific concept. In contrast, as a common-sense concept everyone is able to indicate which sounds are annoying and why they annoy. This paper has a single objective: it aims to couple a number of theoretical concepts to the breadth of responses to the question *“Did you loose/gain something in terms of quality of life when the disturbing sound appeared in your life? If so could you please describe?”* These answers were given in an online questionnaire targeted at sound annoyed persons. At the time of writing the questionnaire is still open and 179 respondents had answered. However, the pattern of these answers matched our theoretical expectations, which were based on the premise that for humans the sound of some sources can interfere with life’s most basic requirement: the need to remain viable.

Lindvall & Radford (1973) proposed that *“Annoyance may be defined as a feeling of displeasure associated with any agent or condition known or believed by an individual or a group to be adversely affecting them*” (Berglund et al. 1994). This paper proposes a more precise definition of the “adverse effect”: namely making it more difficult to self-regulate viability. It starts with an outline of a number of theoretical “ingredients” and their relation to sound annoyance. These ingredients are used to generate a preliminary (sub-)categorization of possible responses. The method section addresses some issues related to the interpretation of the actual responses. The paper ends with a short analysis of the match between the expected answers and the sub-categorization and concluding remarks.

## THEORETICAL MODEL

### Viability preservation and basic needs

People — and animals in general — need to select a continual and varied sequence of actions to remain viable. Remaining viable entails the continual satisfaction of needs and forms the basis of all motivation (Maslow 1943). The basis of Maslow's theory of motivation is that human beings are motivated by unsatisfied needs to remain viable or to become as viable as possible. Maslow argues that certain lower needs have to be satisfied before higher needs can be addressed. In particular he argued that there are basic needs (physiological, safety, love, and esteem), which have to be fulfilled before a person is able to act unselfishly. He called these "deficiency needs." The more a person is able to fulfill these basal needs, the more the needs change toward personal and social growth, and eventually to self-actualization. Although Maslov’s theory is not without critics, only its general theme is required for this paper. In particular we rely on the, undisputed, conclusion that not all needs are equally important and that unsatisfied needs dominate overt behavior.

According to Maslow the satisfaction of basic needs makes or keeps one healthy while preventing need gratification makes one ill or entices one to act selfishly with the purpose to satisfy the need. Maslow’s basic needs are related to each other in a hierarchy of “prepotency”. *“This means that the most prepotent goal will monopolize consciousness and will tend itself to organize the recruitment of the various capacities of the organism. The less prepotent needs are minimized, even forgotten or denied. But when a need is fairly well satisfied, the next prepotent ('higher') need emerges, in turn to dominate the conscious life and to serve as the center of organization of behavior, since gratified needs are not active motivators”* (Maslow 1943).

## Needs and viability enhancing action selection

Maslov gives conscious processing a central role in need satisfaction. Somehow conscious processing optimizes need satisfaction. This dovetails with Dehaene’s analysis of the role of consciousness (Dehaene & Naccache 2001). According to Dehaene *“the more an organism can rely on mental simulation and internal evaluation to select a course of action, instead of acting out in the open world, the lower are the risks and the expenditure of energy*”. Dehaene associates consciousness with a unified neural workspace through which many processes can communicate. Combining Maslow and Dehaene entails that the raison-d’être of cognitive processing and consciousness is the freedom it affords to plan and select viability-preserving and viability-enhancing actions, while balancing available resources, considering multiple time-scales, and taking into account multiple spatial, environmental, and social conditions. This complies with what the WHO defines as health, namely “*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*” (WHO 2011)

## Pleasure, wellbeing and health as indicators

Wellbeing and health indicate successful maintenance of viability, which makes wellbeing and health indicators of a proper match between viability demands, cognitive capabilities, and environmental affordances. Viability can be defined on different timescales: pleasure and displeasure are typically, but not exclusively, short-term indicators. Wellbeing and health are typically mid-term and long-term indicators respectively. On the short term pleasantness is associated with improving viability or maintaining a high state of viability and unpleasantness is associated with deteriorating viability or a state of reduced viability. Pleasure is therefore an indicator of the satisfaction of needs, while displeasure is an indication of unsatisfied needs. The less the need is satisfied, the more it will fill the contents of consciousness and dominate behavior.

## Need satisfaction and emotions

Emotions are also directly associated with need satisfaction. The combination of the dimensions pleasure–displeasure and activation–deactivation (corresponding to the inclination to act) is called core-affect (Russell 2003). Core affect describes a motivational state, which leads to particular forms of *action readiness*: a term that can be defined as emotion (Frijda 1986). This allows a natural coupling between an emotion and behavioral options; for example options afforded by particular sounds (Andringa 2010a). Emotions – defined as action readiness – correspond then to a general strategy to satisfy the need. If the overall strategy changes, the associated emotion changes as well, which is called emotion regulation (Cole et al. 2004). This entails that when someone is stressed he or she might try to come-up with a strategy that re-establishes perceived control. Success in this process is measured in terms of transition to a more pleasurable emotional state.

### Annoyance and irrelevant stimuli

Pleasant stimuli indicate behavioral options that help to maintain or reach high viability. Unpleasant or annoying stimuli either reduce viability or make it more difficult to improve viability. Perception should not be unnecessarily sensitive to irrelevant stimuli and discard them effortlessly if possible. However some “irrelevant” stimuli may require detailed (conscious) processing before they can be deemed irrelevant for viability optimization (Andringa 2010b). While the conscious processing of these stimuli does not contribute to need satisfaction, it requires effortful processing and has therefore a parasitic influence on viability regulation. For a more detailed description of this aspect see Andringa & Lanser (2011).

### Restoration

Attention restoration theory (ART) (Kaplan 1995) proposes that after the prolonged use of effortful directed attention – an attentional state typically associated with work, but which can also be important for pleasurable activities, such as reading a novel – it becomes more difficult to direct attention and to suppress external distractions. Since an attentionally fatigued person is prone to make errors (Staats et al. 2003) and less able to reach desired (mental) goals (i.e., to self-regulate viability) he/she experiences irritability. Being in an environment that does not pose any demands on directed attention provides time for the inhibitory mechanisms involved in directed attention to return towards a normal state. This restores the capacity for directed attention. According to ART four components are important for restoration through suspending directed attention. *“Fascination (use of involuntary, effortless, attention), Being-Away (a physical or cognitive relocation of ones self from everyday activities), Compatibility (a match between the individual’s desired activity/behavior and the environment) and Extent (the scope and connectedness of the environment)*” (Payne 2009). Together these components ensure effortless immersion in an environment that is pleasant, suitable for the current personal goals, and which involves minimal directed attention.

### “Home sweet home”

In terms of viability self-regulation a home is ideally the place to address many levels of Maslov’s hierarchy of needs. At home we satisfy our physiological needs while we eat, drink, and sleep. In addition we satisfy many safety needs in terms of health and well-being and a home is a safety net against accidents and illnesses. In addition homes are places for feelings of love and belonging, especially when we share it with loved ones and when we invite our friends. Houses may even be part of our expression of identity and a source of self-esteem. Finally many homes provide ample opportunities for self-actualization, either implicitly by the activities that it allows or explicitly in the form of rooms optimized for, for example, hobbies.

In addition according to Evans et al. (2003) *“Home is a place that reflects identity and provides security and maximum control. Good housing offers protection not only from the elements but also from negative social conditions. It is a primary territory where we can regulate interpersonal contact. Poor housing quality reduces behavioral options, diminishes mastery, and contributes to a general sense of helplessness.”*

All in all this entails that people in- and explicitly expect that homes should be used for a wide range of need satisfaction activities. In fact it should be a place that is suitable for all of Maslov’s levels of needs, but especially a place where basic needs such as sleep (or more general restoration) could be satisfied. Because this paper is aimed at sound annoyance at home we expect that people might refer to the loss of core-qualities of their home due to sound annoyance.

**Audition-specific properties**

However why (some) sounds may reduce the core-qualities of a home is not directly clear. To understand this relation it is useful to treat hearing and listening as different processes that balance on one hand the need to be sensitive to potentially relevant novel stimuli and on the other hand the need to determine behavioral options afforded by sounds (Andringa 2010b). Hearing is a bottom-up, signal-driven process that helps individuals to "ground in" and "connect to" their environment (e.g., a living room or garden) and to direct their attention to potentially relevant sounds.

Hearing is a background process that is always "on" and it is not under voluntary control. Sometimes the hearing process may deem a stimulus important enough to warrant full conscious analysis, for example because it is particularly loud or otherwise salient or meaningful. This is related to Job's (1999) conclusion about auditory sensitivity: *"two distinct factors appear: one related to loud noises (road traffic, lawn mower), and the other related to quieter noise situations which are nonetheless distracting (rustling papers at the movies, people talking while watching television). More research is needed to address the relationships between these factors, reaction and other health effects."*

Hearing can be contrasted with listening. Listening is a top-down, knowledge and need driven process that allows the perceiver to segregate and group sounds into auditory objects and to allow the activation of appropriate behavioral options. Listening is only possible when conscious and is a form of directed attention (namely directed attention aimed at specific sonic stimuli, which is also called selective attention). Because listening is part of conscious processing it is serial, semantically related to the content of consciousness, and it is in part under voluntary control.

*Sound annoyance occurs when stimuli that are deemed as potentially relevant by the hearing process are evaluated as irrelevant by the listening process.* Because listening involves more effortful selective attention this entails that these (irrelevant) sounds are able to claim part of conscious processing; which means that the individual has lost some of its freedom to self-regulate viability. The impact of this loss depends on the fraction of time attentional resources are not available for desired tasks (which might also be a measure of mental effort).

## PREDICTIONS

This paper addresses the question "Did you loose/gain something in terms of quality of life when the disturbing sound appeared in your life? If so could you please describe?" There are many ways in which a reduction of the options to self-regulate viability may become apparent from verbal reports. Somewhat arbitrarily one might group these in a number of classes such as reports addressing emotions and restoration, attention and perception, loss of core qualities of one's home, health effects, and social factors.

We predict that respondents report that they have difficulty to experience positive emotions or even that they experience more negative emotions. Stress is another emotional indicator because it indicates a lack of perceived control. Somewhat related is when respondents report that they experience either a reduction of opportunities to rest and relax, or even that they actually experience less restoration during the day or a lower quality sleep. Another way to indicate reduced viability self-regulation options is in terms of attention, for example difficulties to concentrate (especially on restorative tasks like reading or listening to quiet music) or attention-related difficulties in other tasks such as working or studying. Associated with this are audition related effects, such as difficulty to hear pleasant ambient sounds (e.g., birds) or difficulties to communicate. In the first case it is more difficult to maintain quiet fascination, in the second case social communication becomes more effortful.

Another broad class of responses pertains to the loss of core qualities of the home and the living environment. The most obvious loss is of quietness due to intruding sounds. But this may extend to a general loss of core qualities of the living environment (such as a loss of rural quality), or a specific loss of options indoors (such as the inability to open windows in summer) and outdoors (such as a less enjoyable garden). Finally it is possible that people report about social aspects or about direct health effects. An overview of these (sub-)categories is given in Table 1.

## METHOD

To test whether the response types of the open question were actually representative for the respondent, we used the first 179 completed questionnaires in the first 6 weeks of an online survey available via www.soundannoyance.com targeted to sound annoyed persons in home situations. The questionnaire is available in Dutch and English. The survey addresses the question: *“Why do some people, whom we may term “sensitized”, end up being highly distracted and annoyed by some sound types, forcing them to listen, rather than just hearing and ignoring the sounds?".* The total questionnaire comprises 84 questions of which maximally 77 were presented to participants. For this paper we used only one question: *“Did you loose/gain something in terms of quality of life when the sound appeared in you life? If so could you please describe?*

In this paper we perform a *qualitative* analysis: namely a check whether the (sub)categories in table 1 cover the breadth of qualitative responses. The analysis was based on 179 completed questionnaires. The main annoying sources for these participants where ‘road traffic’ (23.5 %), ‘aircraft’ (19.0 %) and ‘neighbors’ (16.8 %). Female/Male groups where equally divided (48.6 %) and (50.8 %). The average age was 53. 72 % of the participants was higher educated (minimally college/university).

The open question “*Did you gain something*” was usually answered in terms of the gain of something negative, like: “*I gained a lower quality sleep”* and “*I gained irritation*”. A few were positive: *“More contact with neighbours*” or ambiguous “*We decided to move for more privacy”*. All clearly negative gain formulations were treated as the answer to *“What did you loose in terms of quality of life*”.

The freeform answers are usually concise and easily interpretable, but involve ambiguous details. In general we have followed a “greedy approach” in which we interpreted the answers towards the expectations in Table 1. This was generally quite straightforward, however a number of standard assumptions about the meaning of phrases were applied. For example the phrases “*peace and quiet*”, “*peace and tranquility”*, or variants occurred quite frequently. The phrase is interpreted as a combination as a (peaceful) state-of-mind and a (quiet or tranquil) state of the environment

**Table 1:** Overview of (sub)categories and percentages that the (sub)category was mentioned in the response to the question *“What did you loose in terms of quality of life after the annoying sound appeared in your life”*

| Category | Subcategory | Description | Prevalence | |
|---|---|---|---|---|
| Emotions | | Emotions as action readiness correspond to evaluations of the current state that have to be responded to. | | 42 % |
| | Less pleasure | The reduction of pleasure is a first indication of a viability self-regulation challenge. | 25 % | |
| | More negative emotions | Negative emotions are a sign of a perceived problem to be addressed (quickly if possible). | 11 % | |
| | More stress | Stress is a sign that the perceived problem could not be solved (quickly) and that full restoration is no longer possible. | 6 % | |
| Restoration | | Reduced restoration or options for restoration are a main effect of annoying sounds by making it more difficult to maintain restorative mental states. | | 71 % |
| | Less tranquillity | Disturbing stimuli may suspend restorative states state-of-mind especially of soft fascination tasks (such as reading, listening to quiet music). | 25 % | |
| | Less restoration | This subcategory indicates reduced access to an efficacy known restorative mental states as reading, quiet enjoyment of garden, etc. | 22 % | |
| | Lower quality sleep | Sleep is the most important restorative state. Structural interference with sleep is a direct health threat. | 25 % | |
| Attention | | Intruding sounds may also interfere with mental states that are not necessarily restorative, but important for task performance. | | 15 % |
| | Difficulty to concentrate | A difficulty to concentrate indicates the presences of an “effective” sonic distractor. Especially difficulties to focus on soft fascinating tasks. | 11 % | |
| | Difficulties with other tasks | Sometimes the disturbance might be generally debilitating or preventing one to work at home. | 5 % | |
| Perception | | One of the obvious effects of intrusive sounds is the ability to mask environmental or communicative sounds. Masking of environmental sounds “disconnects” from the environment, while masking communicative sounds makes communication more effortful. | | 6 % |
| Health | | The result of reduced viability self-regulation options is lower health. | | 5 % |
| Change in living conditions | | The home environment is important for viability self-regulation and can be separated in a number of different categories. | | 68 % |
| | Absence of peacefulness | Unwanted sounds may mask or attract attention away from soft background sounds that are characteristic of an undisturbed environment and that we may interpret as peaceful (which is important for restoration). | 15 % | |
| | Loss of environmental quality | Intruding sounds may interfere with essential qualities of the environment, rendering it less suitable for the viability self-regulation purposes. | 8 % | |
| | Less profit of being inside | This refers to the reduced use of the inside of the home for viability regulation (especially restoration). | 18 % | |
| | Less profit of being outside | Refers to the reduced use of, typically, the garden or balcony for viability regulation (especially restoration). | 27 % | |
| Social | | Social aspects of sound annoyance (such as not being taken seriously) tend to exacerbate sound annoyance. | | 11 % |
| | Irritations towards others | This subcategory represents irritation towards individuals, groups, or in general social decision making. | 9 % | |
| | Irritation toward self | Sometimes people are judged as “complainers”. | 1 % | |

allowing a peaceful state-of-mind. We attributed this to less restoration and less tranquillity respectively. A variant of this is “*One needs enough rest, for example to sit calmly in the garden and enjoy*”, which scores on less enjoyment, less tranquility (“*calmly*”), less restoration (“*needs enough rest*”) and less profit of being outside. The sentence “*Rest in the garden/neighbourhood and in the home*” does not score on restoration (although it might pertain to that). Because of the direct connection to the environment it scores on all aspects of a change in living conditions. In general the isolated phrase *"loss of rest*" was assigned both to less restoration and the absence of peacefulness.

The variant "*It steals my silence and my rest*" scores on irritation towards others because stealing is a "social" activity, but it is unclear in this case whether the "it" is the annoying sound or the whole social situation that gave rise to "it". The phrase "it is impossible to relax and read etc. in the garden" scores on less restoration and less profit of being outside. The phrase *"Irritation that I have to avoid consciously*" scores on more negative emotions and difficulty to concentrate because of the conscious effort that cannot be used for self-chosen tasks.

One particular difficulty is the interpretation of the Dutch word "*woongenot*" which may cover all aspects of the "enjoyment of a home". The loss of the enjoyment of a home typically was attributed to less pleasure and to less profit of being inside, even though it might also pertain to the garden.

A number of phrases referred directly to the theme of this paper. For example *"I lost all quality of life*" scores on less pleasure, but makes a deeper point that almost literally reflects the inability to reach or satisfy Maslov's higher needs. The same seems the case with *"Since I moved it is not so bad, but it still dominates my life when I am at home*". A phrase like "*I lost my freedom at home and on my balcony*" scores on the loss of profit of being in- and outside, but it might also refer directly to the title of this paper.

Only 4 answers could not be assigned to any of the predefined (sub-)categories. Two of these referred an equivalent monetary value: *"If I had known this I would not have bought this expensive apartment"* and "*I am willing to pay a lot of money not to be forced to hear the sound of airplanes".*

RESULTS

Each response typically led to 2.1 subcategory scores in table 1. The most important categories were restoration (71 %), change in living conditions (68 %) and emotions (42 %). The subcategories that were mentioned most were less profit of being outside (27 %), less pleasure (25 %), less tranquility (25 %), lower quality sleep (25 %), and less restoration (22 %). Lower health (5 %) was a less important category. This suggests that sound – probably due to the current noise legislation – is a low level stressor without many directly observable health effects, which is consistent with the recent conclusion (WHO 2011) that sound annoyance kills on the long terms through stress-related illnesses in a way that is not easily attributable in individual cases.

Only 6 % mentioned perceptual problems associated with masking of interesting sounds, of these about half were a remark about difficulties listing to speech or music, the other half mentioned the inability to hear normal background sounds. 8 % mentioned the loss of environmental qualities, such as the disturbance of the rural or idyllic quality.

We warn against a use of the quantitative results. This is a qualitative analysis with the purpose to determine whether or not the theoretical model is able to cover the responses. We believe that this can be concluded from the data. Quantitative results are only possible after a more careful design, which allows much more control over the responses. The pattern of responses provides ample indication for a specifically targeted and more detailed analysis.

## CONCLUSION

In this paper we outlined a number of interrelated scientific concepts that pertain to sound annoyance and we checked that these concepts allowed us to cover the breadth of responses when sound annoyed people are asked what they have lost in terms in quality of life after the annoying sound appeared. The whole picture suggests that people talk about what can be interpreted scientifically as 1) reduced restoration through reduced access to restorative attentive states, 2) reduced use of the home environment, especially for restoration, and 3) less positive and more negative emotions, in particular stress. The overall pattern suggests that sound annoyance predominantly reduces the number of options for restoration and other forms of viability self-regulation.

This supports our interpretation of annoying sounds as challenges to self-regulate viability, which allowed us to couple Maslov's theory of motivation, the content of consciousness, emotions as action readiness, displeasure as viability-self-regulation challenge, and wellbeing and health as indicators of successful viability maintenance.

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# The inclusion of cumulative sound exposure in assessment of noise impact on marine mammals

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ABSTRACT

The interest in the effects of acoustic noise for both airborne and underwater species has grown significantly in recent years. Many species are protected from either harm or disturbance by international legislation and/or are of commercial interest. The impact assessment methodologies used to assess these effects often follow those used in airborne acoustics with humans. These include determination of peak pressures (maximum excursion zero-peak positive or negative levels) leading to physiological damage such as temporary / permanent threshold shifts (TTS/PTS) to behavioral response effects such as habitat exclusion, masking effects such as prey / predator avoidance and co-species communication. Other potential effects considered included both direct and indirect non hearing related effects leading to injury and even death such as stranding and induced decompression sickness. In almost all cases very little data exists for very few species.

More recently in the case of marine mammals the inclusion of cumulative sound exposure metrics has begun to emerge (Southall et al. 2007). Data suggests analogies with cumulative sound exposure similar to that seen in humans in air. As a result, assessment of the effects of both temporal and spatial cumulative exposures for many offshore operations are now becoming required. This trend has potentially significant implications to development of offshore industries, such as shipping, petroleum, offshore renewables, etc. Example data is presented of models used to estimate both instantaneous and cumulative SEL levels for an example marine piling sequence in relation to a marine mammal. These models require knowledge of source properties, complex propagation conditions and assumptions about the animal's physiology and its behavioral response. Capabilities and limits of these models are discussed and future needs highlighted in context of future cumulative sound exposure estimate and effects of noise on the marine environment.

# Ultrasonic noise emissions from wind turbines: Potential effects on bat species

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## ABSTRACT

The impact that wind turbines have on the environment, particularly with respect to wildlife such as bat species, has generated increasing concern over the last decade. Although the harnessing of wind power is becoming much more widespread as a clean, renewable energy resource, the increasing global turbine mortality rates for bats are thought to be significantly detrimental to susceptible species. Much research is still needed to fully understand the ways in which turbines affect bats, since they rely on echolocation and audible cues to hunt and navigate, therefore having a unique acoustic perspective of objects in their vicinity. Here we present an overview of what is currently known regarding ultrasonic emissions from operational wind turbine structures, including noise generated from the gearing mechanism, rotor, or through blade defects, and how such noise may be perceptible to some bat species in the local turbine habitat.

## INTRODUCTION

Wind energy is the fastest growing global energy technology, with a yearly growth rate of around 30–40 % (BWEA 2001; EWEA 2009). Wind power is seen as a clean, environmentally friendly renewable energy source; although wind turbines have undergone rapid development over the last 30 years (Twidell 2003), it is only relatively recently that their impact on wildlife has been brought to scientific and public attention. This is perhaps due to their increasingly widespread deployment over a wider range of habitats than ever before, through increasing demand for 'greener' energy production. The phenomenon of wildlife-turbine mortality initially asserted itself with incidents of bird strike at early experimental large-scale turbine installations in the 1980's (Erickson et al. 2002). It was not until early 2000 that bat-strike at wind plants began to be noticed during ground carcass surveys, with many hundreds of bat carcasses turning up, at some plants outnumbering bird carcasses by almost 7:1 (Kerns & Kerlinger 2004). Further study over the last decade has revealed that the phenomenon of bat-turbine mortality is widespread throughout the US, Europe and other countries world-wide. The causality behind bat interactions at wind turbine installations still remains largely unclear, and it is widely recognized that much more study is required to investigate the underlying factors. However, it is recognized that direct blade-strike mortality may not be the only issue for bat populations in the vicinity of wind turbines.

Rather than a visual system, insectivorous bats rely on echolocation, producing high-frequency (ultrasonic) pulses of sound and interpreting reflected echoes to navigate and hunt. It is not yet clearly understood whether operational wind turbine rotors produce significant levels of ultrasonic emission that could be detected by bats, or potentially interfere with echolocation during bat-turbine interactions. This paper provides a brief overview of the current knowledge surrounding noise emissions from wind turbines, and the potential effects on local bat species.

## ULTRASONIC NOISE EMISSIONS FROM WIND TURBINES

Operational turbines are known to produce variable levels of human-audible noise (<20 kHz) from the blades and nacelle. Although turbine noise is predominantly low frequency with almost all acoustic contribution at 65 dB SPL from frequencies below 2 kHz (Dooling 2002), it seems feasible there could also be an ultrasonic component (Johnson & Kunz 2004). To date, there have been very few investigations into the ultrasonic emissions of different makes of turbine. Due to the nature of ultrasound being increasingly attenuated with distance, high-frequency sound emissions from turbines can be difficult to assess, particularly at large-scale installations. Some studies have been unable to detect any ultrasonic noise produced by active turbines, although it is possible that the distance between the turbine blades and ground level was large enough to prevent detection by the equipment used at the time (Johnson & Kunz 2004). Schröder (1997) investigated the ultrasonic emissions of 47 turbines (19 types) in Germany, using a 'Pettersson D980' bat detector, at ground level, between the base to 100 m away. Many turbines were found to emit ultrasound at around 20–50 kHz, although levels were not provided. Although the turbines in this study ranged from 10–92 m tall, there did not appear to be a correlation between ultrasonic emission and turbine size, and the precise source of the ultrasonic noise could not be identified. A similar study by Szewczak & Arnett (2006) examined the ultrasonic emission components of 7 types of turbine at wind plants around the US, as measured by a 'Pettersson D240x' bat detector at ground level. In contrast with Schröder's findings, Szewczak & Arnett found most turbines contributed little, if any, ultrasound above ambient noise level. There therefore appears to be no 'standard' type of ultrasound emission between different makes of turbine, with some structures emitting no ultrasound while others may emit significant levels of ultrasonic noise.

### Potential sources of ultrasonic noise production

According to Twidell (2003), although low-frequency noise can be generated from the turbine's blades passing the tower and perturbing the wind, high-frequency noise may be primarily generated by the blade tips. Some blades are known to 'whistle' due to slight defects in the blade (Dooling 2002), or previous damage. The rotational frequency of the rotor, and its harmonics, can produce unwanted vibrations (Twidell 2003), which could play a part in ultrasonic emission. The internal machinery housed in and around the turbine's nacelle is also reportedly a generic source of noise, and while Szewczak & Arnett (2006) found the electronic machinery of some turbine models to generate ultrasonic noise, in most cases this was not detectable more than 10 m from the nacelle. Such studies have noted that other sources of ultrasonic emissions from the turbines need further investigation.

## EXAMPLE TURBINE NOISE MEASUREMENTS

### Microturbine sound field measurement

Previous work by the authors (Long 2011) assessed the ultrasonic noise emissions from a microturbine model (rotor diameter 0.91 m) previously linked with bat mortality. Measurements were taken with a high-frequency calibrated microphone (assessed frequency range 45–55 kHz), in an anechoic chamber, in 10° increments around the operational rotor (0.6 m from the hub). The microturbine was found not to produce appreciable ultrasonic noise above the undistorted noise floor of the microphone (see Fig. 1).

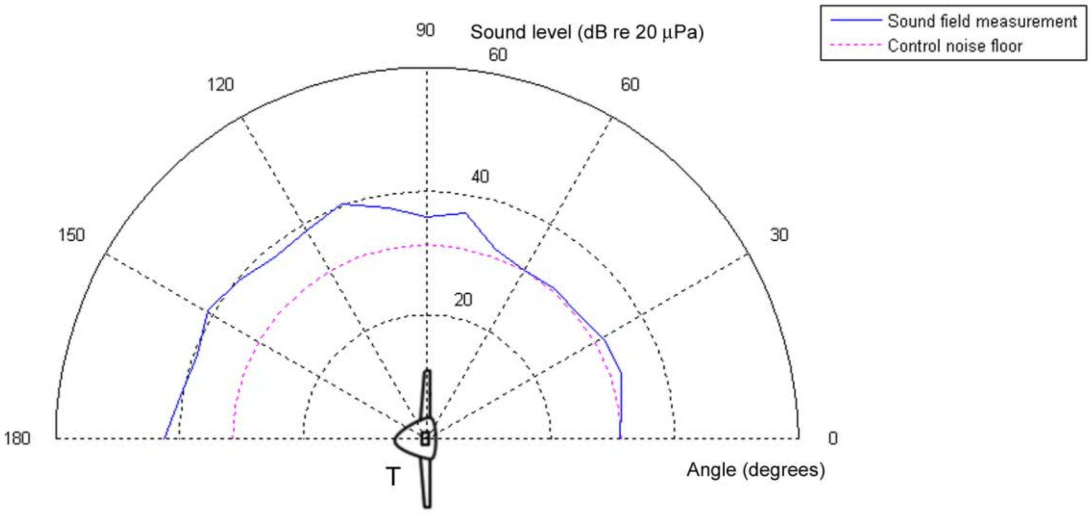


**Figure 1:** Polar sound map of microturbine sound field in the ultrasonic region between 45–55 kHz, as measured by calibrated ultrasonic microphone at a distance of 0.6 m. Solid line indicates the noise measurement, dotted line the control noise floor level for the microphone, while 'T' denotes the location of the microturbine.

It was therefore concluded that this particular model of microturbine did not contribute a high level of ultrasonic noise to the environment in the range of 45–55 kHz. In addition, sonograms of the ultrasonic frequency band recorded (20–100 kHz) revealed no other ultrasonic contribution in this range.

### Unusual turbine blade fault emission

As noted by Dooling (2002), minor blade structural discrepancies/faults can cause operational rotors to 'whistle', either in the human-audible or ultrasonic range. An interesting example of this was recorded from a 20 kW turbine (rotor diameter 11 m) by the authors (Long 2011), using a calibrated high-frequency microphone (assessed frequency range 2 Hz–100 kHz). Ultrasonic FM sweeps were produced by the turbine, between around 22–30 kHz and lasting about 140 ms (see Fig. 2).

By analyzing video footage of the moving blades, these FM sweeps were confirmed to correlate with the passage of one of the turbine's three blades. The owners of the turbine reported that there was one damaged/defective blade that had previously been repaired, but not replaced. Figure 3 highlights the overall amplitude difference between sound emission from the turbine and a control background noise measurement taken in the same location while the turbine was not operational, over the frequency range of the emitted sweep (22–30 kHz).

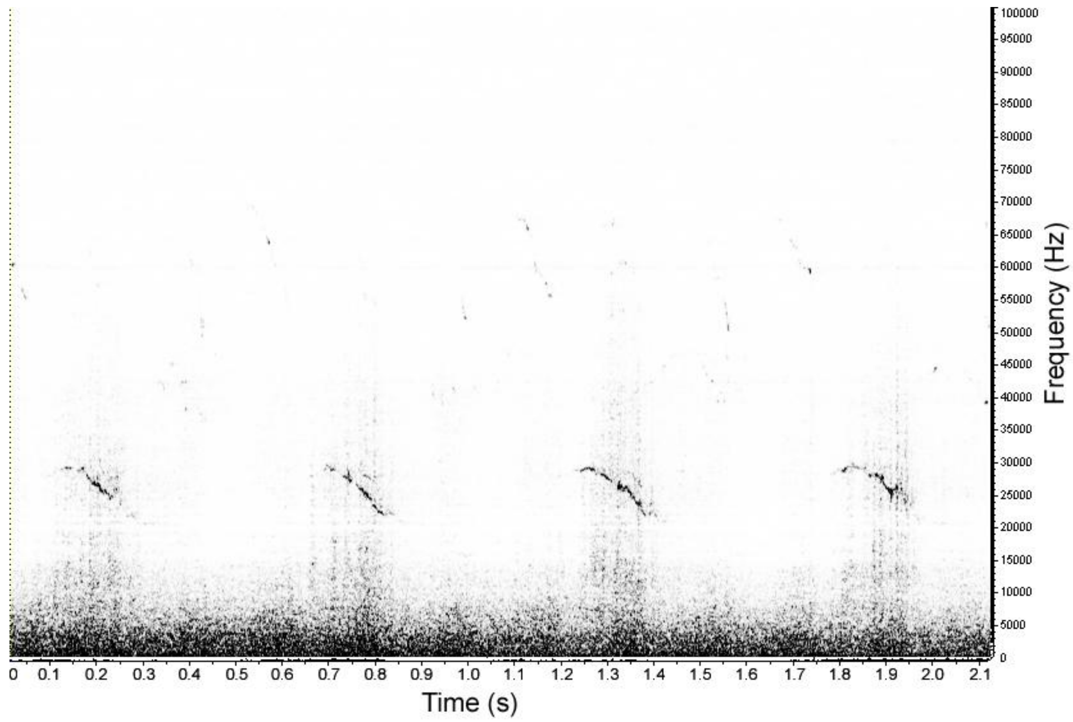


**Figure 2:** Acoustic emission spectral FFT profile from a 20 kW turbine with blade fault, recorded at 200 kS $s^{-1}$ at the turbine base, one metre above ground level (hub height 13 m). Hanning window, FFT length 1024 bands, 75 % overlap, 40 % linear energy scaling.

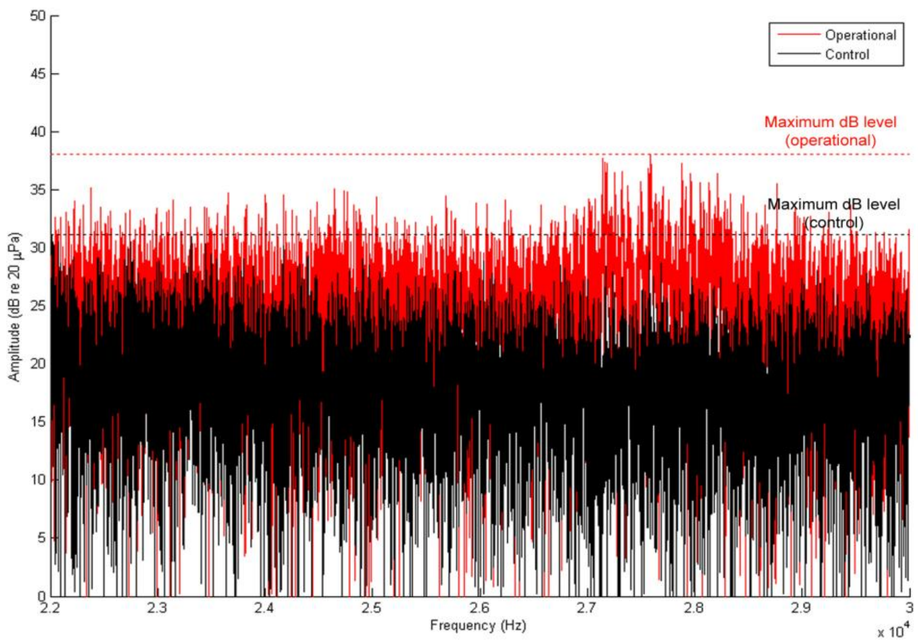


**Figure 3:** DFT trace of the recorded amplitude data comparing a control measurement to that taken during turbine operation, between 22–30 kHz (DFT calculated using MATLAB's FFT algorithm, sampled at 200 kS $s^{-1}$, FFT length 262144 bands). Red and black dotted lines indicate maximum dB levels for the operational and control recordings, respectively. Data taken from 600 ms samples of original recordings (one complete blade sweep cycle).

## POTENTIAL EFFECTS OF TURBINE NOISE ON LOCAL BAT SPECIES

Because bats rely heavily on using and interpreting ultrasound in their environment, potential disruption to their normal behavior patterns due to ultrasound disturbance must be investigated further. It might be speculated that ultrasonic noise emitted in the vicinity of the turbine rotor could potentially 'jam' the ultrasonic emissions of a bat, making it difficult for them to navigate and hunt effectively. Studies in the US have even attempted to deter bats from certain areas by emitting high-intensity broad-band ultrasound, in attempts to 'jam' the bats' echolocation calls (Szewczak & Arnett 2007). The aim was to deploy these devices around turbines, but this method may also compromise the bats' already reduced capacity to interpret their own echoes from moving blades, and avoid them (Long et al. 2010). It has even been suggested that ultrasonic noise itself is attractive to bats (Johnson & Kunz 2004), or at least attracts the curiosity of bats (Arnett et al. 2005), although investigations by Ahlén (2004) to this effect have demonstrated negative results and this hypothesis remains largely unverified (Arnett et al. 2005).

The majority of turbines in Schröder's study (1997) were found to produce ultrasound, typically between 20–50 kHz, which correlates well with frequencies used by European bat species for echolocation (although the sound intensity, and the relationship with bat mortality, were not investigated). Some turbines have a digital anemometer on top of the turbine rotor housing, and these have been found (in some cases) to emit ultrasound themselves in the region of 38 kHz (Arnett et al. 2005), well within the frequency range found to be used by bat species observed in the areas of the study. Arnett and colleagues disabled some of these anemometers and found that there was no effect on the bat mortality rate. The conclusion was reached that these emissions were too readily attenuated to have any effect on the bats present; however the intensity of the emissions from these devices was not measured.

Microturbine sound field assessment by Long (2011) revealed ultrasound levels only slightly above ambient noise (25–40 dB re 20 μPa). Experimental work by Griffin et al. (1960) concluded that sounds produced by small insects of 25–30 dB re 20 μPa at 15 cm were unlikely to be detectable by a bat over 50 cm away, so it seems unlikely that the similar noise level produced by this turbine could be acting as an acoustic lure or masking echolocation. Although this particular microturbine model had been previously linked to bat deaths, it seems unlikely that ultrasound emission played any critical role.

With regard to the ultrasonic noise produced by blade defect, although the predominant ultrasound emissions between 22–30 kHz may be below the detectable range of some of the more common UK bat species, serotine (*Eptesicus serotinus*), Leisler's (*Nyctalus leisleri*) and noctule (*Nyctalus noctula*) bats all echolocate at the lower end of the ultrasonic spectrum, within this range, and may therefore be able to detect this particular turbine's acoustic emission. While the peak amplitude of the emission over this range was over 5 dB re 20 μPa louder than the ambient background noise, the peak was less than 40 dB re 20 μPa in total as measured directly underneath the blades (12 m to hub), and degraded such that it was not discernible above background noise over 20 m away from the source. This can be compared with the relative sound levels produced by the same operational turbine within the human audible range (up to 20 kHz), with a peak of 96 dB re 20 μPa in the <1 kHz zone, as measured at the turbine's base. It is therefore conceivable that some bats could detect the ultrasonic emissions from this particular turbine which are caused by a blade fault.

However, bats in the locality of the turbine may not be able to detect such emissions unless they were in the immediate vicinity, for example within a radius of 10 m, due to the low amplitude of the ultrasound emission and high attenuation.

The impact of ultrasonic emissions on bats is thought by some to be limited, particularly during the summer and during migration (Rodrigues et al. 2006), however this theory remains untested and the way bats react to turbine-produced ultrasound remains unknown (Bach & Rahmel 2004; Bach 2001). Some observations suggest that serotines actually avoid locations where ultrasonic emissions occur, but other bats (such as pipistrelles (*Pipistrellus* spp.)) do not (Bach 2001). It is possible that serotines are able to use ultrasound produced by turbines as an ‘acoustic landmark’ and use this for orientation or avoidance (after Jensen et al. 2005). Dooling (2002) has also hypothesized that turbine-generated noise may help birds (and possibly bats) to better detect and avoid these blades. It is therefore possible that different bat species might detect and utilize ultrasonic noise from turbines in different ways, and that ultrasound emissions may therefore have a variable impact on each species in the locality.

## CONCLUSIONS

Ultrasonic emissions from wind turbines appear to be highly variable and not well investigated. Current research has revealed some turbines do generate ultrasound, either inherently through design or components, or acquired as a result of blade defects. Analysis of this noise has identified the possibility that the ultrasound emissions of such turbines could be perceptible by some bat species, although little is currently known on the long-term effects of ultrasound emission on bat behavior or local bat populations. Existing research suggests that ultrasonic noise produced by wind turbines may have variable effects depending on bat species, something that must be investigated in more detail in order to obtain further insight into potential effects on local bat ecology.

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# Ambient noise doesn't stop at 20 kHz

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ABSTRACT

Noise pollution might be defined as excessive, displeasing human, animal or machine-created environmental noise that disrupts the activity or balance of human or animal life. Most research and legislation in this area is aimed at the impact of noise on human beings, although there are marine regulations aimed at protecting marine mammals from excessive anthropogenic noise. Because of this, airborne noise is generally only considered in the frequency range up to 20 kHz and it may be noted that the A-weighting is not defined above this frequency. A wider frequency range has been investigated in the ocean, but the bulk of underwater ambient noise measurements concentrate on lower frequencies.

Nevertheless, there are many potential sources of higher frequency noise both in the air and under the sea, and there are many animals that are known to possess hearing ranges well into ultrasonic frequencies. The most prolific users of echolocation, bats and dolphins, employ signals extending up to 150 kHz or beyond, while their prey, some moths for example, are able to hear these signals and take evasive action. Additionally, there are many small mammals, such as rats and mice, which communicate using frequencies up to about 50 kHz.

Clearly, animals that use high frequency sound are potentially subject to interference from high frequency noise. However, as little is known about environmental noise at higher frequencies, it is difficult to estimate its effect on these animals, and it is made even more difficult by the rarity of any reliable audiometry for most animals. This paper reviews the little information that is available, assesses the likely impact of both airborne and underwater high frequency noise on creatures with high frequency hearing ranges, and concludes with a discussion of what, if anything, should be done about it.

# The weight of evidence approach in the assessment of hearing impairment induced by noise and ototoxic chemicals

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## INTRODUCTION

There is increasing epidemiological evidence that exposure to some solvents, metals, asphyxiants and other substances is associated in humans with a risk of hearing loss (Miller 1985; Ryback 1992; Morata et al. 1994; Johnson & Nylen 1995; Franks & Morata 1996; Cary et al. 1997; Campo 2004; Fechter 2004; Campo et al. 2009; Johnson & Morata 2010). Data from animal studies suggest ototoxicity of some substances at relatively high concentrations. However, detailed exposure-effect relationships have not yet been identified. Therefore it is difficult to draw any conclusion regarding the effects that might or might not be observed at concentrations relevant for the occupational setting (Cary et al. 1997; Prasher 2002).

This project was undertaken 1) to assess the available data on ototoxicity of chemical substances and consider their relevance to the occupational setting and 2) to organize this information into a structured database indicating potential ototoxicity of industrial chemicals alone or in combination with noise exposure.

## METHODS

Critical toxicological data were compiled for 695 chemical substances included in the Quebec regulation (Regulation Respecting Occupational Health and Safety - RROHS). Information was taken from primary references available in TOXLINE (U.S. National Library of Medicine, National Institutes of Health) database up to July 2009. For each study the following parameters were taken into account: studied species, number of subjects or animals, exposure route, characteristics of control groups, exposure levels, audiometric and statistical tests, dose/effect relationship and when available, mechanisms of action. The data were evaluated only for chemical exposure concentrations up to the short-term exposure limit (STEV) or ceiling value (CV) or five times the 8-h time weighted average exposure value (TWAEV) for human data. In the RROHS, STEV is defined as the maximum concentration to which workers can be exposed for a period of 15 minutes; TWAEV represents the average concentration of a given chemical to which workers can be exposed for normal 8-h workdays, 5 days a week. For animal studies, the limit was set at 100 times the 8-h TWA OEL (occupational exposure level) or ceiling value. Concerning the noise exposure, a level of 75 dBA during 8 h was considered as a NOAEL (No Observed Adverse Effect Level) and subjects were considered “without noise exposure” (ISO-1999 1990).

We built a weight of evidence table (Table 1) to combine the information from both human and animal studies on ototoxicity of chemicals and their interaction with noise. Human data were given more weight in the overall assessment. For example, a "strong" evidence from animal studies combined with an "absence" of evidence from the available human studies yielded a "medium" evidence overall. At first, a weight of evidence qualifier was given for both the ototoxicity and the interaction with noise: "strong", "medium", "weak", "absent" or "no study found". Note that weight of evidence qualifier "absent" should not be regarded as evidence that a substance is not ototoxic or that it does not interact with noise. Regarding the final conclusion about the ototoxic potential of substances or their interaction with noise, a substance bearing an overall qualifier of "strong evidence" of ototoxicity or interaction with noise was considered as an "ototoxic substance" or as a substance for which there is an "evidence of interaction" with noise. Those with "medium evidence" overall were rated "possibly ototoxic" or "possible interaction". We considered the ototoxic potential of those with only "weak evidence" as "non-conclusive". Finally, those for which there was absence of evidence bore the mention "no evidence" of ototoxicity or interaction with noise.

## RESULTS

In total, 224 experiments (in 150 articles), of which 51 (in 44 articles) evaluate simultaneous exposure to noise and a chemical) covering 29 substances were assessed using a weight of evidence approach. The information was organized to create a data sheet for each study (available in both French and English). These datasheets can be accessed at the following address:

http://www.dsest.umontreal.ca/recherche_rayonnement/ototoxicity_en.html

Table 2 presents a summary of conclusions about ototoxic effects of industrial chemicals without a concomitant exposure to noise. Among 29 substances, 7 were identified as ototoxic or potentially ototoxic. For ten substances (acrylonitrile, n-butyl alcohol, carbon disulfide, cyanides, n-heptane, mercury (vapors, alkyl compounds and inorganic compounds), alpha-methyl styrene, parathion, trimethyl tin and welding fumes), the lack of toxicological data did not allow a definitive conclusion to be reached. Eleven substances (p-tert-butyltoluene, carbone monoxide, enflurane, hexachlorobenzene, hydrogen cyanide, methyl chloroform, methylene chloride, nicotine, perchloroethylene and ethyl alcohol) were considered as non-ototoxic.

For nine substances, the assessment was based on only one study, thus limiting the reliability of the toxicological assessment. On the other extreme, the assessment of toluene was based on 36 studies.

Table 3 gives a summary of conclusions about interactions of industrial chemicals with noise. Relevant data for eleven substances were found. Toluene is identified as an ototoxic agent that can also interact with noise to induce more severe hearing losses. Carbon monoxide is considered as a possible potentiator of noise-induced hearing loss. For seven substances, the lack of toxicological data did not allow a definitive conclusion to be reached and for two substances there is no evidence of interaction with noise. For seven substances, the assessment was based on only one study, thus limiting the reliability of the toxicological assessment. On the other extreme, the assessment of carbon monoxide was based on 18 studies.

**Table 1:** Weight of evidence approach for the assessment of ototoxicity and interaction with noise of industrial chemicals

| Weight of evidence of studies | | | Conclusion | |
|---|---|---|---|---|
| **Human studies** | **Animal studies** | **Overall** | **Ototoxicity** | **Interaction with noise** |
| S | S | S | O | I |
| S | M | S | O | I |
| S | W | S | O | I |
| S | A | S | O | I |
| S | X | S | O | I |
| M | S | S | O | I |
| M | M | M | PO | PI |
| M | W | M | PO | PI |
| M | A | M | PO | PI |
| M | X | M | PO | PI |
| W | S | M | PO | PI |
| W | M | W | NC | NC |
| W | W | W | NC | NC |
| W | A | W | NC | NC |
| W | X | W | NC | NC |
| A | S | M | PO | PI |
| A | M | W | NC | NC |
| A | W | W | NC | NC |
| A | A | A | NE | NE |
| A | X | A | NE | NE |
| X | S | M | PO | PI |
| X | M | W | NC | NC |
| X | W | W | NC | NC |
| X | A | A | NE | NE |
| X | X | X | X | X |

**Strength of evidence about ototoxicity or interaction substance/noise**: **S** = Strong; **M** = Medium; **W**= Weak; **A** = Absent; **X** = No study found

**Conclusion about ototoxicity**: **O** = Ototoxic substance; **PO** = Possibly ototoxic substance; **NC** = Non conclusive; **NE** = No evidence; **X** = No documentation

**Conclusion about the interaction substance/noise**: **I** = Evidence of interaction; **PI** = Possible interaction; **NC** = Non conclusive; **NE** = No evidence; **X** = No documentation

**Table 2:** Summary of conclusions about ototoxic effects of industrial chemicals

| Industrial chemical | Occupational exposure level* | | Weight of evidence | | | Conclusion ototoxicity |
|---|---|---|---|---|---|---|
| | Quebec TWAEV (STEV) | ACGIH TWA (STEL) | Human studies | Animal studies | Overall | |
| **Ototoxic** | | | | | | |
| Lead | 0.05 mg/m$^3$ | 0.05 mg/m$^3$ | S | X | S | O |
| Styrene | 50 (100) | 20 (40) | M | S | S | O |
| Toluene | 50 | 50 | M | S | S | O |
| Trichloroethylene | 50 (200) | 50 (100) | M | S | S | O** |
| **Possibly ototoxic** | | | | | | |
| Ethylbenzene | 100 (125) | 100 (125) | X | S | M | PO |
| n-Hexane | 50 | 50 | W | S | M | PO** |
| Xylene | 100 (150) | 100 (150) | A | S | M | PO |

* in ppm; **ototoxic and neurotoxic effects on the auditory system; (see Table 1 for abbreviations)

**Table 3:** Summary of conclusions about interactions of industrial chemicals with noise

| Industrial chemical | Occupational exposure level* | | Weight of evidence | | | Conclusion interaction |
|---|---|---|---|---|---|---|
| | Quebec TWAEV (STEV) | ACGIH TWA (STEL) | Human studies | Animal studies | Overall | |
| **Interaction with noise** | | | | | | |
| Toluene | 50 | 50 | S | M | S | I |
| **Possible interaction with noise** | | | | | | |
| Carbon monoxide | 35 (200) | 25 | X | S | M | PI |
| **Non conclusive** | | | | | | |
| Acrylonitrile | 2 | 2 | X | M | W | NC |
| Carbon disulfide | 4 (12) | 1 | W | X | W | NC |
| Ethyl benzene | 100 (125) | 100 (125) | X | W | W | NC |
| Hydrogen cyanide and cyanide salts | 10 | 4.7 mg/m$^3$ | X | W | W | NC |
| Styrene | 50 (100) | 20 (40) | W | M | W | NC |
| Trichloroethylene | 50 (200) | 50 (100) | X | W | W | NC |
| Welding fumes | 5 mg/m$^3$ | | X | W | W | NC |
| **No evidence** | | | | | | |
| Lead | 0.05 mg/m$^3$ | 0.05 mg/m$^3$ | A | X | A | NE |
| Nicotine | 0.5 mg/m$^3$ | 0.5 mg/m$^3$ | X | A | A | NE |

* in ppm; (see Table 1 for abbreviations)

The analysis also showed that a wide variety of tests are used to identify adverse effects on hearing: pure-tone audiometry, reflex modification audiometry, distorsion product otoacoustic emissions, transiently evoked otoacoustic emissions, multisensory conditioned avoidance response task, electrocochleography and auditory evoked brainstem responses. Exposure to industrial chemicals was also documented with different approaches and, in the cases of lead, toluene and styrene, biological monitoring has been used.

## CONCLUSIONS

For the large majority of substances, epidemiology studies looking at a toxicological dimension are rare. In many studies, absence of detailed data about noise exposure and the exposure to all chemical contaminants is a common problem. This is the most important barrier to reach an appropriate conclusion about ototoxicity (or absence of). The evaluation of the effect of exposure to a single substance is particularly challenging because workers are usually exposed to a cocktail of various chemicals. In addition, there is a long list of confounding factors that need to be addressed: physical contaminants: noise, vibrations, ototoxic medications, including diuretics and salicylates, noise exposure during leisure activities and individual factors (age, gender, tobacco, alcohol, drugs and genetics).

For the majority of cases where potential ototoxicity was previously highlighted, there is a paucity of toxicological data in the primary literature. Human and animal studies indicate that lead, styrene, toluene and trichloroethylene are ototoxic and ethyl benzene, n-hexane and xylene are possibly ototoxic at concentrations that are relevant to the occupational setting. Toluene and possibly carbon monoxide appear to exacerbate noise-induced hearing impairment. Toluene interacts with noise to induce more severe hearing losses than noise alone.

## FUNDING

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# Perceived quality of the living environment and noise

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## INTRODUCTION

In those regions of the world where primary living conditions are good and basic needs are easily fulfilled, the perceived quality of the local living environment is of growing concern. Traffic has an important impact on this perceived quality of the local living environment and as such also on the mental well-being of the population (Guite et al., 2006). Traffic influences the life of people in different ways: on the one hand, traffic is inevitable to guarantee accessibility to various types of functions, on the other hand, traffic noise, traffic emissions, road safety, etc. threaten health and well-being. Assessing this complex interplay requires a set of indicators (Botteldooren and Lercher, 2006) and suitable aggregation models (Botteldooren et al., 2006). It was previously noted that environmental sound plays an important role (Botteldooren et al., 2011) in the perceived quality of the living environment both in a positive and a negative way and therefore several of these indicators may be related to environmental sound.

Existing models tend to evaluate traffic liveability at specific dwelling locations on the basis of the characteristics of the nearest street (road width, bicycle facilities, etc.) and its traffic (e.g. traffic flow, traffic speed). The living environment is however not limited to the house and garden. Subjective assessment of the sonic environment may include the wider neighbourhood (Klaboe et al., 2005) or relax the adverse effect at home (Gidlof-Gunnarsson, A. and Ohrstrom, E. 2007). The effect of exposure during trips is even more pronounced for air quality where it was shown that in some cases the majority of exposure to air pollution and in particular to fine and ultrafine particles occurred while away from home (Int Panis et al., 2010). A model capable of quantifying the quality of the living environment should therefore not only take into account the dwelling but also the routes giving access to the dwelling and the nearby public space. For some aspects it may even be required to include an assessment of usual destinations such as the work environment.

Based on the above observations a model was designed by first unravelling the constituents of quality of life and then focussing on the factors that might be influenced by traffic – the result is sometimes referred to as traffic liveability. Then a methodology is proposed that has as a main focus to achieve a better quantification of exposure to different types of traffic impacts by including not only the exposure at the home address, but also the impacts during activities at other locations and the impacts during trips.

In this paper the proposed model is briefly described, before presenting some of the first results for the case-study of Ghent.

## MODEL DESCRIPTION

### Selection of an indicator set for 'traffic livability'

Existing methods split down the 'traffic livability' into the separate impacts, and define a set of indicators for each of them. As these indicators are usually assessed separately or at most aggregated by source, combined effects are not included in a straight forward way and neither is distributed exposure. The proposed model puts the person at the centre of the picture. Quality of life or well-being is explored and unravelled in basic components. By focussing on the role of the living environment and more specifically on the effect of traffic in it, a traffic liveability indicator is obtained. It has four components: accessibility of basic functions, health impact (traffic emissions, sleep disturbance, …), effects on the living environment (noise annoyance, visual impact, …) and effects on the social functioning of the neighbourhood (barrier effects). Each component is divided into some partial effects with their own specific indicators (Figure 1). Measuring traffic livability is realized by measuring the indicators and aggregating them to a global score.

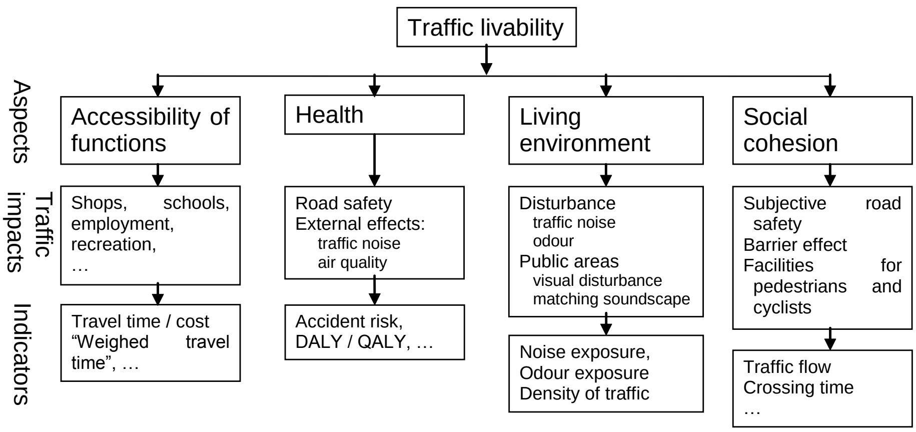



**Figure 1:** Definition of traffic livability, containing several types of traffic impacts, each with their own indicators

For the aggregation from the separate indicators to an appreciation of each aspect, and from the aspects to a global traffic livability evaluation, the Choquet integration is applied (Botteldooren et al., 2006). This method makes a weighted sum, giving most weight to the strongest components. This simulates human perception, as one extreme (positive or negative) aspect will dominate the perception and will rarely be compensated by one or more moderately good or bad criteria. This way, the model combines advantages from a weighted sum and a strongest component aggregation.

### Methodology for the evaluation of the indicators

Rather than to assess the quality of the living environment using a dwelling based approach, the individual is used as a starting point. This implies the following choices:

- Traffic livability is measured by means of a broad set of indicators, representing different types of traffic impacts (accessibility, traffic noise, traffic emissions, …). As such combined effects, positive and negative, are automatically included in the methodology.

- The evaluation is not done for an average person, but takes into account individual needs and travel patterns, sampled from the Flemish large-scale trip survey. This means that personal characteristics (age, marital status, professional activities, …) and family characteristics (number and age of children, car availability, …) and the consequent diverse mobility needs, are incorporated in the evaluation.
- The methodology reflects the daily activity pattern and trip pattern. Beside the traffic impacts at home, also the effects during the trips and at the destinations are included in the evaluation. This means that the evaluation of traffic livability covers the complete living neighbourhood, rather than limiting it to the dwelling itself or the street it is located in.

### The trip behaviour survey

A major input to the model is the statistical trip behaviour of the population under study. For the area under study, the Flemish Trip Behaviour Survey (Onderzoek VerplaatsingsGedrag, OVG), a large scale survey collecting trip data by means of trip diaries covering the whole of Flanders, is used. The survey data consist of three data sets containing the family characteristics, the person characteristics and the personal trip data. The survey has been executed in 1994-1995 (OVG-1), in 2000-2001 (OVG-2) and in 2007-2008 (OVG-3) (Ministerie van de Vlaamse Gemeenschap, 1996, 2004, 2009).

OVG-1 and OVG-2 used the ‘family’ as basic entity. The surveys covered 2.500 families each, surveying all family members, representing about 8.000 persons. The methodology in this paper was elaborated using the data from these surveys. In the most recent trip survey OVG-3 the methodology was slightly modified: the survey now used ‘persons’ as the basic entity. It was therefore not used in the model.

### Evaluation of the indicators by sampling the trip behaviour

As explained, the model starts from a person and all the trips it makes, the modes it uses and the destinations these trips lead to. As this information is not available on a person by person basis, a Monte Carlo simulation is used sampling random families and/or persons from the trip behaviour survey. The proposed methodology involves the following steps:

- First of all, a random household is sampled from the trip database. In the database a large set of characteristics are available about the household (composition, car availability, …), its members (age, income, …) and their daily trips (number, purpose, distance, …). These parameters can be taken into account during the later evaluation, to simulate specific desires and appreciations. In the current stage this sampling is done completely random, but in a later stage some specific parameters could be taken into account to sample for example younger or older families, larger or smaller families, rather mediated or not, etc. according to the neighbourhood characteristics.
- For all the trips that are reported by this household, the next step is to select a logical destination. This destination is again sampled from a database of possible destinations per trip purpose. For school trips for example one of the schools in the area will be selected, for shopping trips one of the shops. GIS layers containing these data need to be collected for the area under study.

- For the collected trips, travel modes and destinations, the third step is to calculate a logical route from the dwelling to the destination. A standard route finding method can be used for this.
- Knowing the house location, destination locations, routes and transportation modes of all the trips and activities of each household member, it is possible to evaluate the effect traffic has on this person's life, health, and well being including these whereabouts.

By sampling a sufficient number of dwellings per street segment (or a sufficient number of households per dwelling), this method results in an aggregated perception of traffic livability, representing a realistic variety of activity patterns and transportation needs and covering the complete living space of the population, rather than just the dwelling location.

### Estimating the demand for local traffic

As a by product of the trip model, the routes of all local car trips, bicycle trips and pedestrian trips can be totalized to an estimation for the local traffic generation by car, by bicycle and on foot.

For car traffic, this local traffic can be a valuable addition to the existing macroscopic traffic models, which focus on the main roads, and therefore lack detail about the local traffic on minor streets. This allows for a more accurate estimate of noise and air pollution levels in the urban area.

For bicycles and pedestrians, the method allows the estimation of the intensity and routes of the local bicycle and pedestrian flows, based on the local needs and destinations. This is important information for the evaluation of network quality.

## CASE-STUDY FOR THE CITY OF GHENT

### Area under study

The case study focuses on the city of Ghent, a 230 000 inhabitant city in Belgium. The study area includes the city centre as well as the surrounding suburbs. This ensures that different types of areas (more dense, more suburban), roads (from highway level, over major roads and ring roads to purely local roads) and livability problems (traffic noise, barrier effect, traffic safety, …) are included.

### Results

By means of some of the intermediate results the operation of the model is illustrated before focussing on the model results.

The fundamental model input consists of a set of GIS-layers concerning the road network (road design, bicycle infrastructure, ...), origin and destination points (dwelling locations, shops, schools, ...). Spatial traffic impacts (traffic noise, air quality, road accidents, ...) can be calculated as part of the model but as they were available, they were not recalculated in this case study. Another major input is the database from the Flemish Travel Behaviour Survey.

In the first part of the model, a household is sampled for each of the dwellings to be evaluated. Using the reported trip behaviour, a set of logical trip destinations is sampled, and the routes for the given travel modes are calculated. This first steps results in maps as shown in Figure 2, showing the simulated trips for two sampled households.

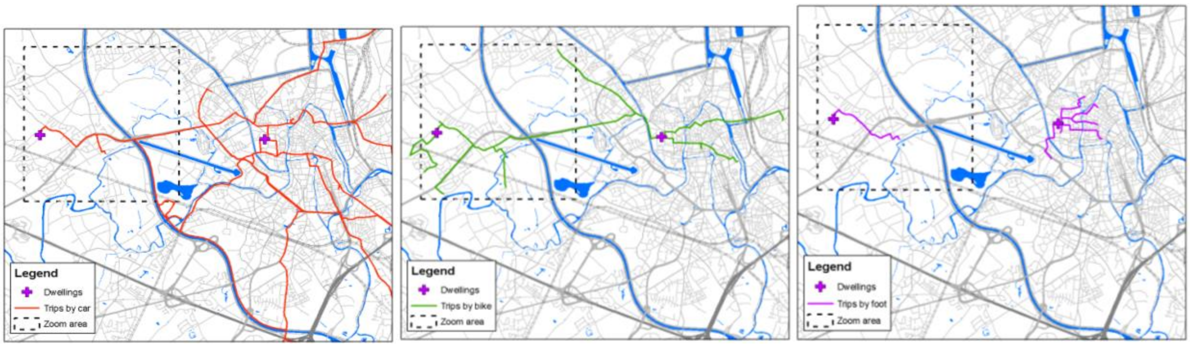



**Figure 2:** The calculated routes by the sampled households in two dwellings, including the trips by car (left), by bike (middle) and on foot (right)

In the next part of the model, the indicators for traffic livability will be evaluated by means of overlays of these routes with ‘emission layers’ of the different indicators (traffic noise, traffic emissions, traffic safety, …), considering the dwelling location, the destination location and the route and mode of the trip. This way, a large set of indicators is evaluated, covering several aspects of traffic livability. Each indicator is evaluated for each sampled person living in the area under study. In the following aggregation step, the separate indicators are aggregated thematically. Traffic noise is incorporated in the model in two ways: it has an impact on the “Health” aspect (for the health effects by traffic noise, including sleep disturbance) and on the “Living environment” aspect (for the perceived annoyance by traffic noise).

To present the results in the maps below a spatial average over all families living in a 200 m by 200 m area is calculated.

The evaluation of the health effects takes into account several types of traffic impacts. Figure 2 shows two of them: the health effects of road traffic noise and of traffic emissions. The map shows that the health impact of traffic noise is mainly concentrated in the south of the city, because of the concentration of two highways with the main entrance road to the city centre and the ring road. The map of the health effects of air quality shows that the highest effects are concentrated along the two highways in the south and along the main entrance to the city centre. It also shows a moderate not well localised effect in the city centre which is probably due to exposure during trips.

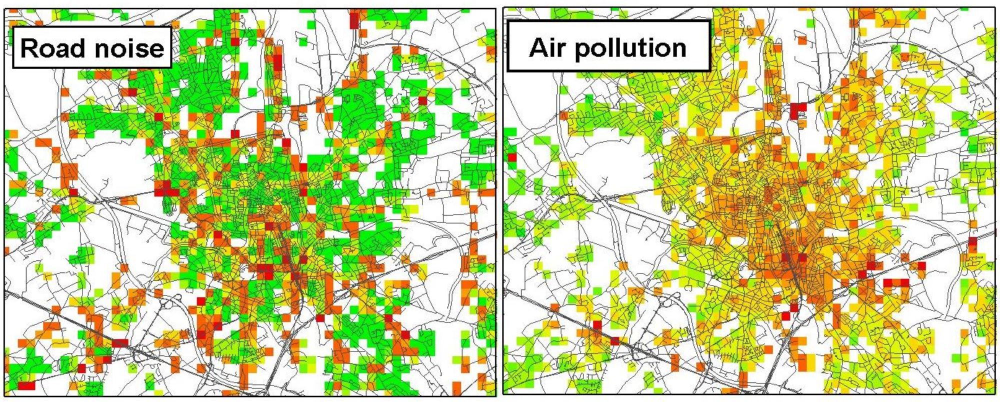



**Figure 2:** Illustrations of the health effects of traffic: a model plot showing good (green) to bad (red) evaluation of the health impact by road traffic noise (left) and traffic emissions (right)

The indicator “living environment” is mainly influenced by several types of annoyance. Figure 3 shows the annoyance caused by traffic noise and by traffic bustle. Whereas the first includes mainly annoyance at home, the latter also includes the annoyance because of traffic bustle during (the first part of) the trips from home, therefore covering the wider environment of the dwelling. Comparing the two maps, two differences can be observed. On the one hand the highways and main traffic arteries are an important source of traffic noise, but do not appear in relation to traffic bustle as they are not directly accessible from the dwelling. On the other hand many inhabitants live in quiet residential streets, with little annoyance by traffic noise, but do perceive the impact of traffic (bustle) as soon as they leave home (during trips) resulting in a larger area where this aspect of traffic liveability of moderate.

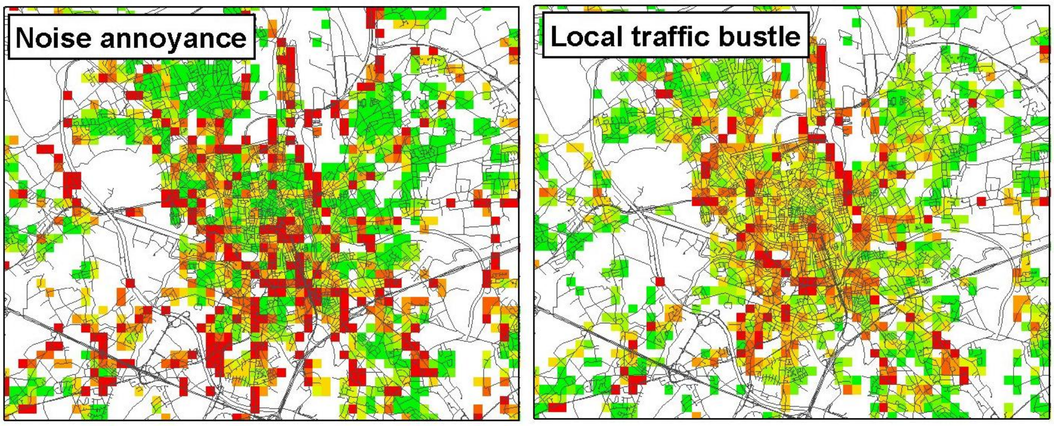



**Figure 3:** Illustrations of the effects of traffic on the living environment: a model plot showing good (green) to bad (red) evaluation of the annoyance by traffic noise (left) and traffic bustle (right)

The resulting total appreciation of traffic livability is presented in Figure 5. Again some well-known problem areas appear from this plot, such as the inner city ring road, some radial arteries and the highways and railroads passing near the city. As one could expect the overall indicator; less extremes are observed since it seems all neighbourhoods have at least some positive aspects.

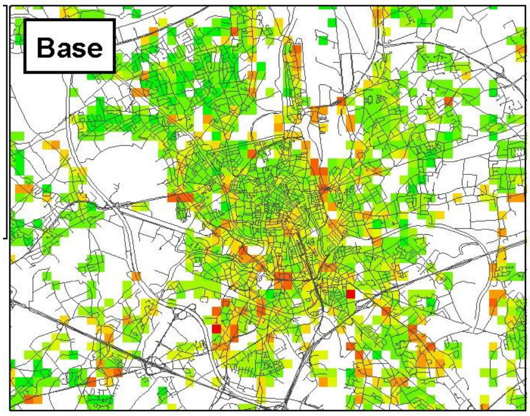



**Figure 4:** Map of the average traffic livability, green = good, red = bad

## Relation to the reported satisfaction

In order to assess the quality of the proposed model, the model results are compared to the data from a Livability Survey (SLO, “Schriftelijk Leefbaarheids-Onderzoek”). This large scale survey asks people from the whole of Flanders –amongst others – to report their appreciation of their living environment on a five point bipolar scale. For the further analysis, only the survey data from the Ghent area are used.

In Figure 6 the resulting traffic livability appreciation from the survey and the model are grouped into five satisfaction classes. Figure 6a shows that the traffic livability model gives a very good reproduction of the reported satisfaction from the SLO-survey: the majority of the people (about 65%) are satisfied to very satisfied (classes 1 and 2) while only 10% states to be dissatisfied or (very) dissatisfied (classes -1 and -2).

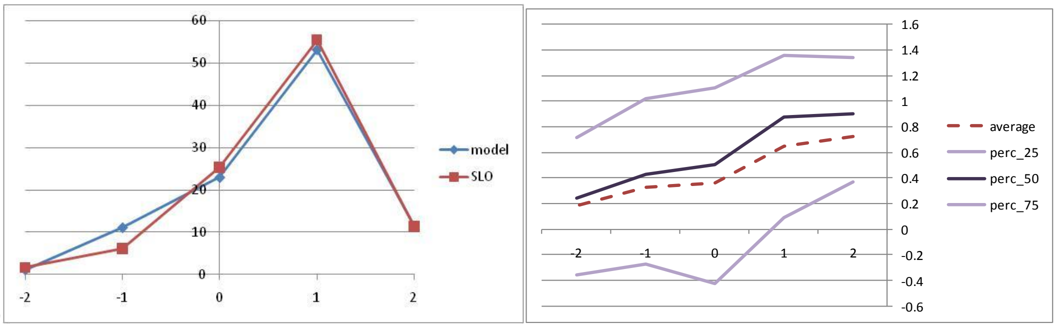
a)  b)


**Figure 5:** a) Frequency distribution of the traffic livability evaluation according to the traffic livability model and the reported satisfaction in the SLO-survey; b) Relationship between the reported satisfaction from the SLO-survey (x-axis) and the calculated evaluation (y-axis) according to the traffic livability model, showing the average and median value and the 25- and 75-percentile values

For a more detailed comparison of the results, the model results are reduced in order to make both sets geographically comparable. The dwellings of participants of the SLO-surveys are located, and from the model only the simulated persons that are in the immediate vicinity of the SLO-surveys are retained. This guarantees that both datasets represent the same geographical dwelling locations. The model results are split into five classes, according to the reported satisfaction in the corresponding SLO-survey dwelling. This allows comparing the calculated traffic livability to the reported satisfaction. The results are visualized in Figure 6b, where the horizontal axis contains the reported satisfaction (SLO-survey) and the vertical axis shows the statistical indicators of calculated appreciation according the model.

From this comparison it can be concluded that the model reproduces extremely accurately the statistical distribution of reported appreciation of the living environment. On an individual basis, the prediction has to be imprecise because of the random factors involved in reproducing the trips and route choice.This explains the large spread in Figure 6b. The average trend between reported and modelled quality of the living environment is however still monotonous.

## CONCLUSIONS

In this paper, an innovating model is presented for objectively assessing traffic livability. Whereas classic methods focus on the traffic impacts at the dwelling location, the proposed method puts the person in the centre and incorporates the whole activity pattern, and the corresponding trip behaviour in the evaluation. This is reached by a Monte Carlo simulation of households, including their reported trip behaviour, according to a trip behaviour survey.

By construction, the model should outperform other approaches because it includes known effects such as the influence of the wider neighbourhood or exposure to air pollution during trips. The model accounts for positive as well as negative effects of traffic and in particular it accounts for them at the level of an individual. Combined exposure is accounted for on a trip by trip basis and saturation effects are accounted for on a person by person basis because of the Choquet integral used in the aggregation. Thus it can be expected that the non-physiologic part of effects of combined exposure is accounted for.

Application of the traffic livability model in a case-study for the city of Ghent, shows that the model offers a realistic reproduction of the reported satisfaction with the living environment obtained from a Flemish livability survey on a statistical level. The model is not suitable for predicting an individual's appreciation of the living environment since trip behaviour and choice of destinations is only included on a statistical basis.

The model can be used to evaluate a set of policy scenarios that affect infrastructure, traffic management, land use, or even personal behaviour.

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# Environmental exposure – annoyance relationships in black and gray urban areas

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It is quite seldom to find individuals who are only annoyed by a single type of urban environmental exposure, and extremely rare to find individuals that cherish or complain about only a single aspect of urban living quality. In black and gray urban areas exposed to high and intermediate noise levels, people are usually multi-exposed and react adversely to more than one type of environmental exposure. Nevertheless, different classes of exposures and aspects of urban life are often studied in isolation, and exposure-annoyance relationships estimated separately and with disregard of urban context. Measures to reduce and alleviate the various quality of life impacts are also often undertaken by authorities focusing on one type of exposure at a time. In this paper we summarize some results and insights from Norwegian socio-acoustic and socio-environmental research containing elements of a broader conceptual framework.

## INTRODUCTION

In the 1996 EC green paper on noise exposure and the cost to society defined three noise exposure classes (EC 1996). Black areas that have an equivalent exposure level of $L_{den}$ above 65 dBA, gray areas levels lie between 55 dBA and 65 dBA, whereas green areas have noise levels below 55 dBA. According to the EEA 60 % of the EC population exposed to more than 55 dB live in gray areas (EEA 1999). This is somewhat less than the ca. 70 % estimated in the Green Paper –See Figure 1.

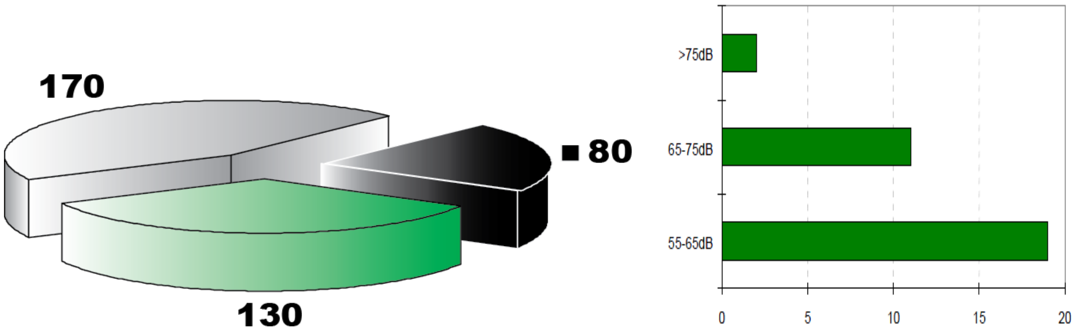


**Figure 1:** Share of citizens in different exposure intervals ($L_{den}$), EC 1996, EEA: http://www.eea.europa.eu/data-and-maps/figures/estimated-percentage-of-population-exposed-to-different-road-trafic-noise-levels

Both The Netherlands and Norway have information on the changes in population noise impacts over time (Berg 2011; Statistics Norway 2007). With the caveat that there are several methodological challenges in comparing noise exposure over time, both sets seem to confirm the finding in the EC 1996 green paper that "*the numbers of those acutely exposed are decreasing but the overall problem is getting worse*".
Modern policies to reduce noise in urban areas thus need to address noise problems in gray areas. I argue here that this means taking more of the urban context into account and to cherish the benefits of reducing annoyance for all citizens -- not only those severely annoyed.

## NOISE EXPOSURE AT THE FACADE NOT SUFFICIENT

Exposure-annoyance curves for road traffic noise employing the noise level on the most exposed facade of an apartment or dwelling show a consistent increase in annoyance with increasing exposure (Miedema & Oudshoorn 2001). However, the spread of annoyance responses for a given exposure interval e.g. 60-65 dBA is great - See Figure 2 Left panel. It is well known that individual noise sensitivity is uncorrelated with noise exposure and has an impact equal to that of 10 dB. However, when noise sensitivity is entered as a simple moderating factor in exposure--annoyance relationship models each sensitivity group exhibits the same (horizontally shifted) spread in responses. We must consequently look elsewhere if we want to explain more of the variability in annoyance responses at a given level of noise exposure. In this paper we focus on urban situations where people seldom are only exposed to one environmental exposure. The Norwegian Survey on Life Quality feature questions on a few additional exposures such as dust and grime and exhaust/odor in addition to noise from road traffic, rail traffic and aircrafts. Most respondents are at least a little annoyed from at least one other exposure. About a quarter of the population are highly annoyed by two or more exposures – see Figure 2: Right panel (Kolbenstvedt & Klæboe 2002).

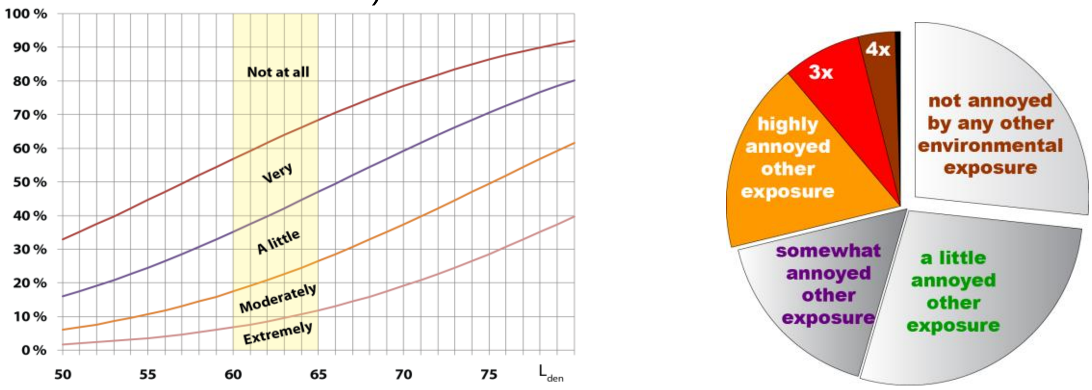


**Figure 2: Left panel** Exposure annoyance relationships (based on (Miedema & Oudshoorn 2001). **Right panel:** Number of annoyance combinations reported in social survey

In this paper we collate results from Norwegian papers, some published in air pollution journals, on contextual factors such as vehicular air pollution exposure and neighborhood noisescapes and their impact on noise annoyance For a recent review of international studies on the impact of combined agents – see Lercher (2011).

## THE NORWEGIAN STUDIES

The Norwegian research program “Traffic and the Environment” started 25 years ago and lasted 20 years. The prime motivating factor for its unique design was to view noise, air pollution, insecurity, and barrier effects from road traffic as a whole. Studying air pollution annoyance met opposition. It broke with the traditional focus in the field of air pollution epidemiology of concentrating on more narrowly defined health effects (Evans et al. 1988), and the calculated values of the indicators of the exposures in question ($NO_2$, $PM_{10}$) were deemed insignificant/difficult/impossible to perceive.

The studies revealed that people become annoyed from air pollution, and respond to ambient air pollution by keeping doors and windows shut, and by refraining from using their balconies or outdoor areas. They visit parks and venture outdoors less often than they otherwise would. These are the same type of behavioral adaptations or coping activities exhibited by residents exposed to noise.

Exposure-annoyance relationships relating annoyance with indicators of $NO_2$, $PM_{10}$, and $PM_{2.5}$ were subsequently established for the first three surveys in the Oslo Area Klæboe (Klæboe et al. 2000) and thereafter expanded with two follow up studies in the city of Drammen (Amundsen et al. 2008).

All exposure-annoyance relationships for air pollution annoyance display narrow bands of error with respect to average population responses – see Figure 3. The exposure indicators in these studies were 3 month averages based on hourly calculations using actual meteorological data (e.g. that the wind direction is such that air pollution from a busy street during the rush hour affected a given dwelling location). The calculations were checked against measurement station time series (Clench-Aas et al. 2000). The indicators are here all used as indicators of the ambient pollution mix. It should be noted that though the average pollution indicators were highly correlated and also correlated well with the 98-percentile exposure indicators. The narrow error bands from the multi-year/multi-site study - see Figure 3 top and bottom left panels -- indicate that these air pollution component indicators must be well correlated with those air pollution components actually causing the annoyance.

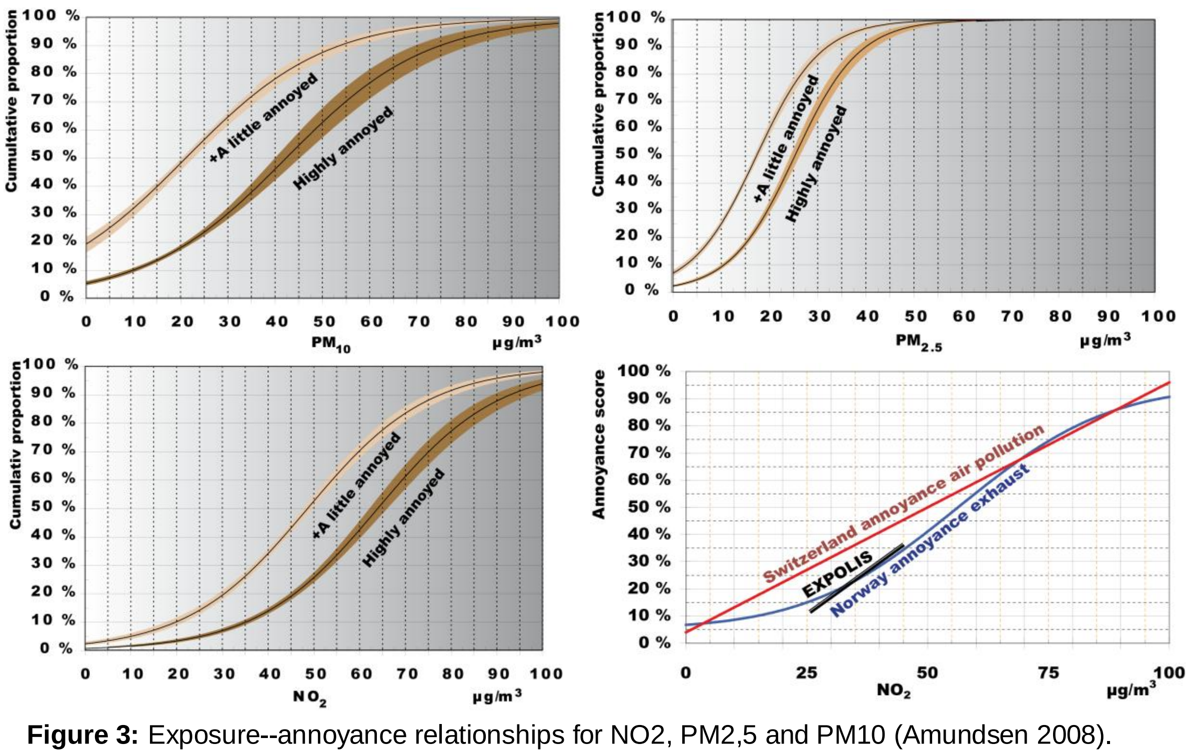


**Figure 3:** Exposure--annoyance relationships for NO2, PM2,5 and PM10 (Amundsen 2008). Comparison of European annoyance score results) - lower right panel (Klæboe 2008)

There are relatively few European studies that specifically look at residential annoyance with air pollution. However, the estimated exposure-annoyance relationships from these studies are roughly similar (Atari et al. 2009; Forsberg et al. 1997; Jacquemin et al. 2008; Klæboe et al. 2008; Modig & Forsberg 2007; Oglesby et al. 2000; Rotko et al. 2002).

Having established that people's annoyance with dust/grime and exhaust/odor are intimately linked to ambient air-pollution levels in urban areas, the next question is whether annoyance with air pollution could affect people's reactions to noise and vice versa. We need to examine the correlation between noise and air pollutant indicators, and, if possible, statistically analyze whether there are combined impacts.

### Combined impacts of noise and air pollution

People near busy roads can be shielded from noise by having a dwelling that faces a courtyard or a silent side. These apartments will none the less be exposed to relatively high air pollution exposure levels. Vice versa -- dwellings located on the front side of a house very close to a road with moderate traffic, can have relatively high noise exposure due to the closeness to the traffic whereas the local contribution of vehicular emissions to overall ambient air pollution concentrations is negligible. In addition there are regional and climatic factors that affect air pollution and not noise. In the Oslo studies it was concluded that the correlation between noise exposure and air pollution was not very high (50 %). The low correlations are ideal for using multivariate regression models to separate the impacts of noise and air pollution and study their interaction.

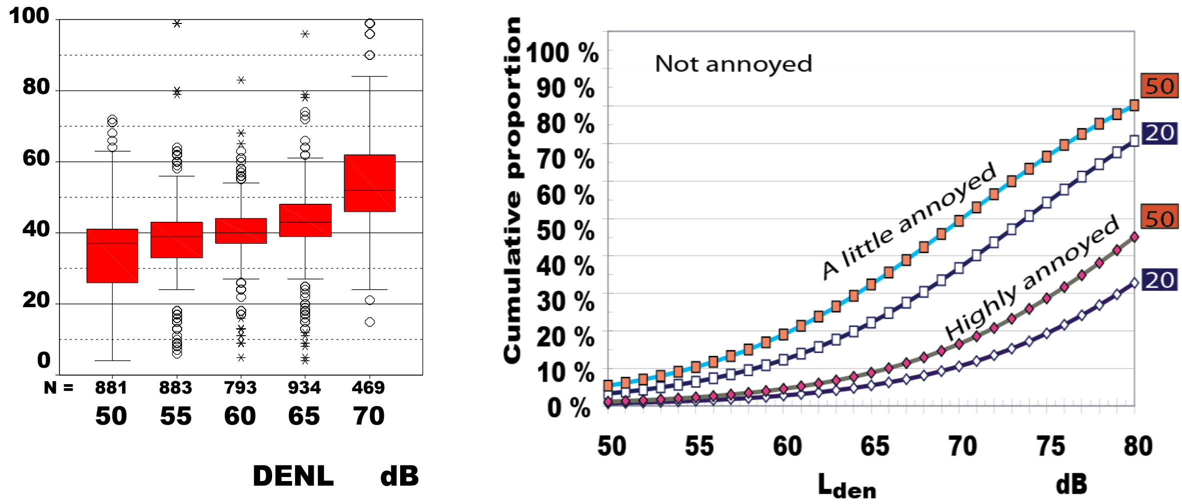


**Figure 4:** Variation in air pollution exposure for different noise exposure intervals.The estimated modifying effect of higher levels of air pollution (Clench-Aas et al. 2000; Klæboe et al. 2000).

From the Oslo studies the conclusion from such multivariate regression models was that *"... the higher the road traffic noise levels people are exposed to, the more likely they are to be highly annoyed by exhaust smell at a specified air pollution level. The higher air pollution levels people are exposed to the more likely they are to be annoyed by road traffic noise at a specified noise level." (Klæboe et al. 2000)*

### The Neighborhood noisescape

In soundscape research the focus has been on public and private areas with relative quiet, and where sound quality, and not only the amount of noise, matters. We can perhaps better use the term dwelling "noisescape" to describe the spatial distribution of high levels of noise in the immediate vicinity of an apartment and apartment residents encounter when walking, cycling, playing, waiting for public transport, visiting neighbors, shopping locally etc.

The focus in the Norwegian studies was on arterial or ring roads that cut through residential areas with courtyard building structures. Here the noise levels in the neighborhood can vary a great deal over short distances. (Klæboe 2007; Klæboe et al. 2005, 2006).

Utilizing information from noise calculations on the emissions affecting sidewalks and outdoor areas, and spatial routines of geographical information systems it was possible to ascertain how much noisier or quieter the noisescape was in relation to the single point residential exposure indicator (Klæboe 2007; Klæboe et al. 2005).

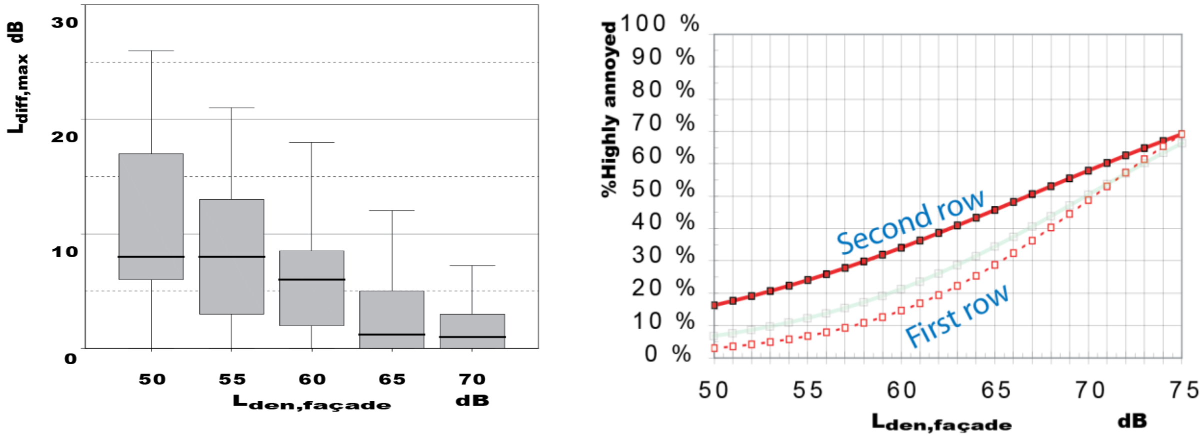


**Figure 5:** Box plots of how much noisier the neighborhood is relative to the noise level at the apartment (Klaeboe et al. 2005). Exposure effect relationships for front row and second row apartments

That the neighborhood soundscape can vary quite a lot for apartments having the same exposure on the facade is evident from Figure 5. Dwellings facing a side street or court yard that benefit from the shielding provided by the intervening buildings, are still left with a neighborhood noisescape that is worse than the matching front row situation with less traffic. In the former case the exposure indicator is a bad indicator of the relevant noisescape. In the latter case the noisescape conforms more to what could be expected from the facade exposure indicator.

Dwellings or apartments exposed to a high noise level on the facade usually have a noisier neighborhood than those exposed to lower levels. This average relationship is captured by exposure-annoyance relationships used in the EC (Miedema & Oudshoorn 2001). However, the impact of having a noisier or less noisy neighborhood than usual will not be captured. From the results of multivariate regression models it can be shown that annoyance for second row situations lies above that when the dwelling is in a front row situation -- see Figure 5 - right panel. The advantage of taking the noisescape into account when assessing noise annoyance, is estimated to be "worth" the equivalent of a 3 dB exposure adjustment to the facade exposure indicator for more than 30 % of the dwellings (Klæboe 2007; Klæboe et al. 2006) .

For noise mitigation policies in urban areas the difference in annoyance reactions depending on the contextual influence of the dwelling noisescape means that more (not less) of the urban noise problem is associated with busy roads cutting through residential areas, and consequently that traffic management, silent road surfaces, and noise screens have two separate beneficial effects:

A) They reduce the noise levels on the facades (taken into account today).

B) They improve the neighborhood soundscape of dwellings in the second and third row more than is captured by the change in facade exposure indicator.

It becomes more attractive to reduce noise along densely populated urban streets with courtyard buildings than areas where front row situations are more common.

### Changes in noise annoyance reductions after traffic changes

When the amount of traffic changes, not only do noise emissions change, but air pollution levels, vibrations, and the dwelling noisescapes change as well. To the degree that these changes are of the same size as those usually associated with changes in the level of traffic they are already captured in average exposure effect relationships. A "noise" exposure indicator is representative of all factors correlated with traffic - not only noise on the facade. Why then do reactions to noise exposure change when traffic changes (Brown & van Kamp 2009).

The answer provided by the Oslo Studies is that the relative quality of the neighborhood and air quality improve more than what could be expected from the facade noise changes - see Figure 6 left panel for a visual illustration of the improvement in noisescape. Here the facade exposure is held constant, allowing us to examine the change in the relative quality of the noisescape. In addition to the noise reductions affecting the dwellings, the noisescape associated with a given exposure on the facade has been improved.

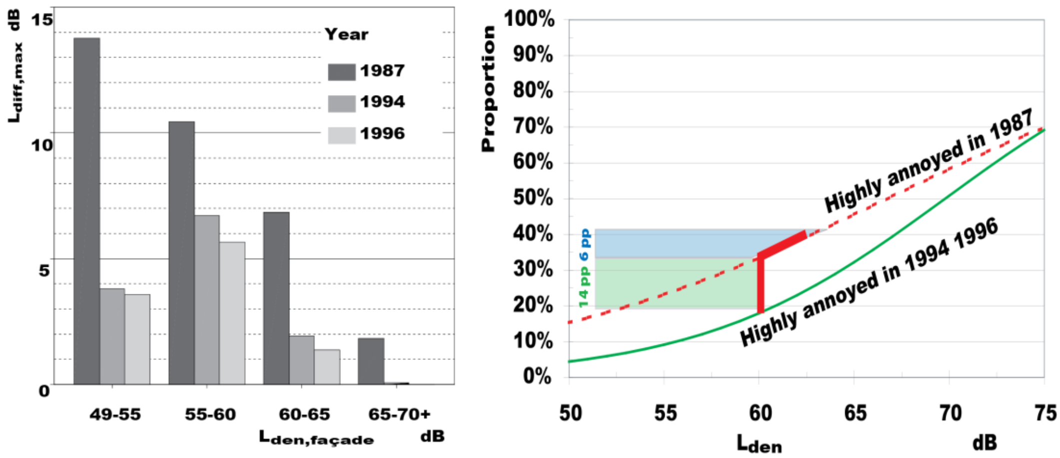


**Figure 6:** How much noisier the neighbourhood of dwellings in different 5 dB exposure intervals, are before and after traffic changes. **Right panel** changes in noise annoyance after traffic reductions Based on: (Klæboe et al. 2000, 2005) respectively.

From the Oslo studies it became also clear that the changes in the exposure to air pollution also changed more after traffic reductions than could be expected from the noise changes. The changes in traffic affected the whole surrounding area, not only the particular street responsible for the noise emissions. This had a larger effect on overall air pollution levels than noise. The size of annoyance reductions after traffic changes thus consists of two components:

1. The reduction that could be expected from the curve for the before situation, and
2. The downwards shift in exposure-annoyance relationship due to the air pollution and noisescape improvements in the area – see Figure 6 Right Panel.

**Should we only count citizens that are seriously annoyed?**

Due to the size of the gray areas, the metrics for counting population annoyance is important. The Norwegian noise annoyance index (NAI) counts population annoyance by applying exposure--annoyance relationships to national noise mapping data. Each citizen's degree of annoyance is given an annoyance score on a scale from 0 to 100 % and the total population annoyance obtained by aggregating. Two persons 50 % annoyed count as much as one 100 % annoyed. I have previously argued that this puts too much weight on lower degrees of annoyance (Klaeboe 2011).

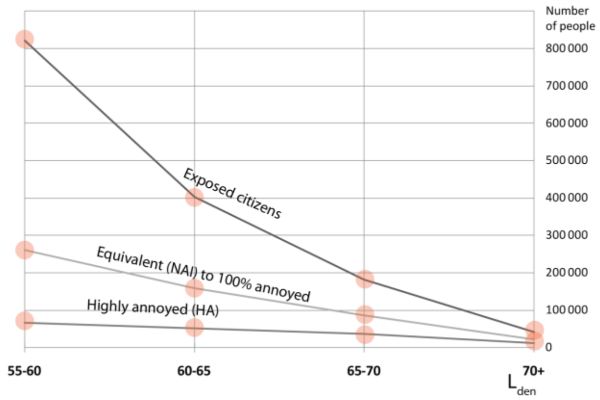


**Figure 7:** The number of exposed citizens, Norwegian noise index (NAI) and number highly annoyed by noise exposure. National noise mapping (Statistics Norway 2007)

However, it is possible to go too far in the opposite direction. Counting only people who are seriously/highly annoyed, neglects the substantial adverse effect road traffic noise has on people's daily life in terms of sleep, rest, and activity interferences (also present at noise exposure levels below 55 dBA). People who are moderately annoyed experience noise qualitatively in much the same way as those seriously annoyed. All exposure--effect relationships for annoyance and activity interference show the same gradual continuous slopes with increasing exposure.

A probabilistic understanding of how ill health in gray areas come about - as the result of the interaction between individual disposition, physiological variability, and multiple stressors across different life arenas, argues against using a severity index of zero for other than those seriously annoyed.

An unintended consequence of confining the WHO health definition to only include severe annoyance - for a discussion see Hollander (2011) - is that efforts to reduce noise exposure in gray areas will be viewed as less effective. Traffic management, efforts to deploy silent road surfaces, measures to reduce the propagation of noise by noise barriers, surface treatments or vegetation will seem to have fewer benefits than they have, and it will be become more difficult to motivate their deployment. Focusing only on those who are highly annoyed could thus be of disservice to the very group one seeks to protect the most.

CONCLUSIONS

Noise control policies in black areas have met with some success, and – due to the European Noise Directive and the Soundscape movement, there is a new vigor in the efforts to protect and improve sound quality in green areas. However, there is also a case to be made for modern noise control policies specifically addressing noise in conjunction with other environmental impacts in gray areas. To do so successfully, it has been argued here that it is necessary to view noise exposure and noise impacts in a broader urban context. It could be further argued that since gray areas are the typical situation facing urban planners, research to produce tools and methods for dealing successfully with multisource and multi-exposure situations must also be a priority.

Adopting a more holistic perspective on urban exposures improves the chances of undertaking successful interventions, and sharing the cost of these among all groups benefiting from measures. Traffic management and traffic reductions produce multiple benefits as do green walls, roofs, and vegetation. Counting all types of benefits – not only noise reduction at the façade, and valuing both larger and smaller benefits cannot other than improve the chances of more being done to improve life quality and health of European citizens.

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# Multi-sensory experience in urban historical places

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## INTRODUCTION

Community responses to noise are shown to be highly relevant to soundscape assessment, but to be able to understand how soundscape can influence people behavior and preferences, a multi-sensory analysis is necessary (Zhang & Kang 2005).

The concept could be turned in *livingscape*. The multi-sensory nature of *livingscape* (urban blight, soundscape, light-scape, thermal-scape, subjective user responses) assessments is acknowledged by a case study whereby the response to the sound is also based upon other sensory and behavioral elements, rather than the sound *per se*.

Subjective environmental perceptions and objective measures (addressing acoustical, lighting and thermal parameters) data were collected in St. Salvario, an historical district in Turin, during summer 2010 and winter 2011. From a historical analysis thirteen key-spaces were selected on site which characterize past and present soundscape of the district subdivided in nodes, paths and edges/borders (La Malva & Astolfi 2010).

In this work only a part of the overall study is presented. Thirteen factors were singled out from the factorial analysis on environmental data collected *in situ* based on 33 measurement parameters. Significant correlation ($p<0.01$) among the thirteen factors and the subjective items related to environmental perception and pleasantness related to day/night-time and summer/winter period were carried out (La Malva et al. 2011a, b).

Interaction plots related to day/night-time and summer/winter period visualize the key-spaces behaviors for the different environmental factors and the pleasantness answers emerging from the questionnaires.

Research aims at demonstrating the influence on assessing urban soundscapes of individual and demographic similarities/differences, people's behavior, physical aspects of the soundscape, other sensory and environmental elements, and the general location and context.

## METHOD

Perceptual strategies are recognized as an important component in improving the quality of life in cities. "Urban quality" is an important support to urban planning and management which was carried out through the *livingscape* approach (urban blight, soundscape, light-scape, thermal-scape, questionnaires) within the historic district 'San Salvario' in Turin.

To account for the multidimensional character of the urban quality in towns, an integrated analysis of three aspects was addressed, as shown in Figure 1, involving: 1) psychometric tools to measure the perception of environmental quality; 2) different aspects related to the urban blight (both in architectural and environmental terms); 3) objective investigation of environmental quality through the measurement of acoustic, light, thermal and IAQ physical parameters.

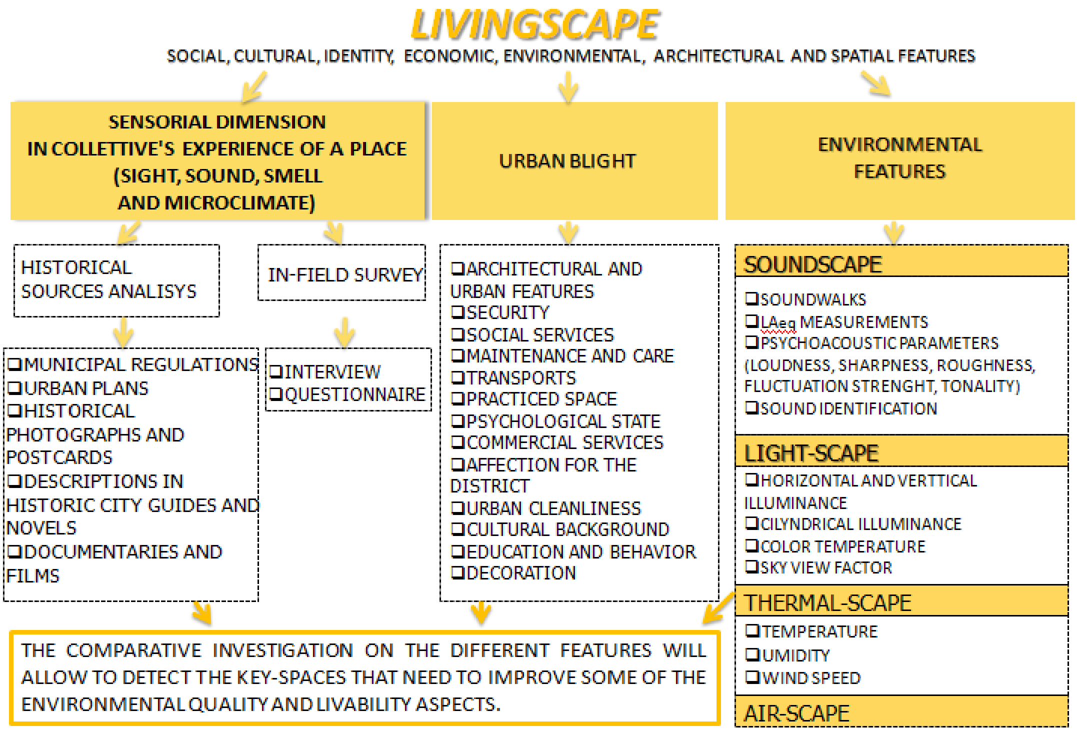



**Figure 1:** Livingscape approach based on the integrated analysis of three aspects: collective perception of environmental quality, urban blight and objective investigation of environmental aspects (acoustic, light, thermal and IAQ physical parameters)

From a previous study carried out by the authors on a number of different historic sources (archival, cartographic, literary and documentary) from the 19th century onwards, it was possible to understand variations in the human dimension of perception (sight, sound, smell and microclimate) in Turin, with particular attention to the district of San Salvario.

From this analysis, 13 key-spaces (10 streets, 2 squares and an arcade) were selected as meaningful to characterize past and present district soundscape (Figure 2) and divided in nodes, paths and edges/borders based on Lynch's the mental mapping approach. The key-spaces were subdivided into 30 m long parts (Di Gabriele et al. 2010): for every part, urban blight evaluations, environmental measurements and user judgments through questionnaires (soundscape, light-scape, thermal-scape) were carried out to investigate the *livingscape*.

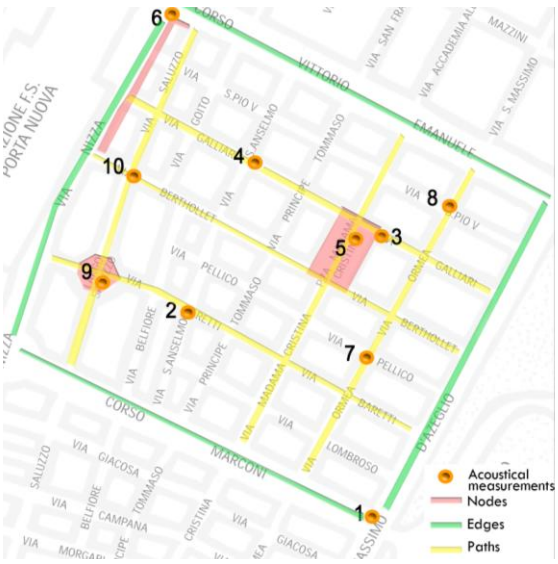



**Figure 2:** Key-spaces and acoustical measurement points visualized on the map of San Salvario [nodes: n.1 market square (5), n.2 Saluzzo square (9) and n.3 arcades (6)]

## MEASUREMENT OF THE *LIVINGSCAPE*

The measurements of the *acoustical parameters* were carried out through many soundwalks during the daytime (10 a.m. – 2 p.m.) and the nighttime (7 p.m. – 2 a.m.). To investigate the key-spaces, binaural audio signals (16 bit/44.1 kHz) were recorded with a portable two-channel device "M-Audio Microtrack 24/96" and with binaural headphones “Sennheiser MKE 2002”. A total of 40 binaural recording files of 10-15 minutes and 40 punctual noise levels 10 minutes long were measured during summer and winter period, in the daytime and nighttime. The files were then uploaded to the elaboration software dBSonic to calculate the Leq [dBA] and psychoacoustic parameter for each part: Loudness *N* [sone], Sharpness *S* [acum], Roughness *R* [cAsper] and Fluctuation strength *F* [cVacil] in time. Global analysis of all the measurements helps us to understand the behavior of the psychoacoustical parameters in the urban public places (De Coensel et al. 2003).

For the *light-scape parameters* horizontal (H ill.), vertical (V ill.) cylindrical illuminance (C ill.) levels and the correlated color temperature (CCT) were measured every 60 m with luxmeter. Daylight penetration within the urban spaces has been recognized as an important quality factor that requires means of preservation, especially in very dense cities. The Sky View Factor (SVF), calculated with the Ecotect software, is a measure of solid angle view of the sky from an urban space. A SVF of 1 means that there is an unobstructed view of the sky. A SVF of 0 means that the view of the sky is totally obstructed, and thus the temperatures will be strongly influenced by the urban context (Littlefair et al. 2000).

Air temperature, air velocity and relative humidity were collected every 60 meters to detect the *thermal-scape parameters.*

Photo and video acquisition were carried out in situ at the same time. On the other hand the acquired photo and video data were used together with the GIS data and satellite images to construct realistic representations. All the collected datum were uploaded to a GIS software (ArcGis 9.0), being connected to each key-space (La Malva et al. 2011c).

A *slenderness index* (SI) - as geometrical parameter - was defined as a ratio of the mean ground elevation of the buildings and the width of the road.

For the *urban blight investigation* 46 statements were analyzed based on a 5-point scale (1-*unpleasant to 5-extremely pleasant*) and concerning livability and quality of life architectural and urban assessments, social life, physical environment, security, activities and utilities, place identity and site arrangement.

Environmental perception and well-being were delineated through the analysis of the *questionnaires* submitted to the users of the area in the same points of the in-field measurements. It consisted of 51 items, divided in two sections, one regarding general background information (gender, age and number of years spent in urban areas etc.), frequentation and identity of the place, quality of life in the district and one aimed at collecting judgments on environmental perceptions (acoustic, light, thermal and air quality) and pleasantness, calmness/relaxation, vibrancy (Cain et al. 2010). Both a 5 and 10-step rating scale (with a semantic descriptor for each step) and continuous scales, with semantic descriptors placed at the extremes, were used for the subjective investigation. A total of 496 questionnaires was filled in.

## RESULTS

A factorial analysis was carried out using SPSS® package v.15 with varimax rotation (with Kaiser normalization) on measurements data in order to extract the number of factors and to identify which descriptors loaded most highly on each environmental factor. The analysis was carried out considering the summer/winter period and the day/night-time together. Only for the visual environment analysis the day/night-time was separated considering the difference related to daylight and artificial light. Table 1 presents as example the rotated component matrix on 15 acoustical objective parameters. The factors emerging from the analysis don't explain significant difference in the clustered dimensions.

**Table 1:** Results of the factor analysis of data. Bold italic values represent the most significant weights for each factors.

| Soundscape components | | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| NISO [Sone] | ***.974*** | .111 | .111 | .094 |
| Lmean [dB] | ***.965*** | .119 | .073 | .055 |
| Nmean [Sone] | ***.964*** | -.055 | .068 | .101 |
| $N_{10}$ [Sone] | ***.963*** | -.015 | .061 | .103 |
| Nmax [Sone] | ***.874*** | .359 | .153 | .047 |
| Lmax [dB] | ***.830*** | .407 | .195 | .027 |
| $F_{10}$ [cVacil] | .157 | ***.906*** | .121 | .222 |
| Fmax [cVacil] | .127 | ***.882*** | .221 | .054 |
| Fmean [cVacil] | .126 | ***.881*** | .061 | .269 |
| $S_{10}$ [acum] | .138 | .142 | ***.931*** | .003 |
| Smean [acum] | .302 | .005 | ***.895*** | -.047 |
| Smax [acum] | -.060 | .209 | ***.726*** | .090 |
| $R_{10}$ [cAsper] | .431 | .241 | -.041 | ***.806*** |
| Rmax [cAsper] | -.188 | .237 | .102 | ***.794*** |
| Rmean [cAsper] | .643 | .109 | -.042 | ***.705*** |

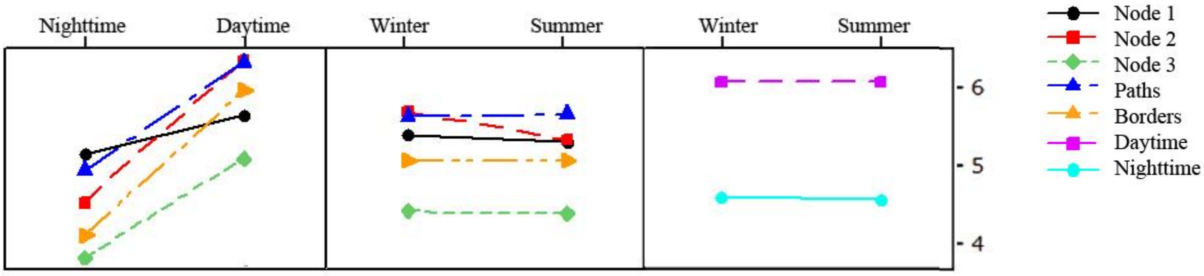
The factorial analysis singled out four acoustical factors explaining the 85.7 % of the variance. These factors can be associated to four different sound aspects: 1."Intensity" (6 items), 2."Fluctuation" (3), 3."Sharpness" (3) and 4."Roughness" (3).

Subjective scores were then correlated to the environmental factor scores, with the aim to investigate the relationships among environmental quality and pleasantness. Table 2 shows the most significant correlation (p<0.01) among the four acoustical factors and the subjective items related to the sound environment perception and pleasantness related to day/night-time and summer/winter periods.

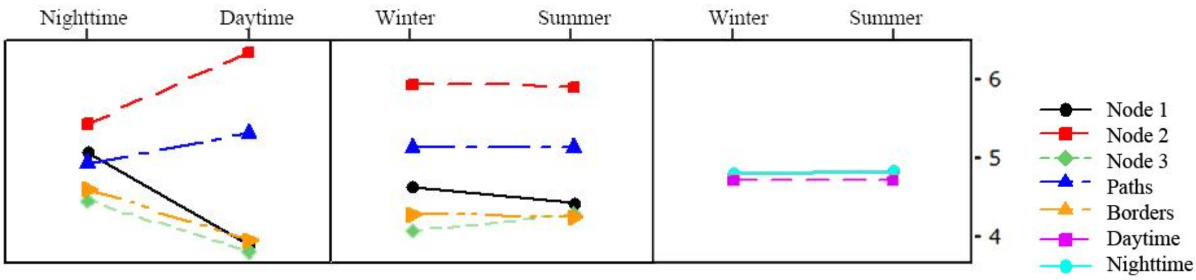
**Table 2:** Significant correlations (p<0.01) among the 4 acoustical factors and the subjective items related to the sounds perception and pleasantness in day/night-time and summer/winter periods.

| **SOUNDSCAPE FACTOR** | Noise annoyance (a) | Noise annoyance (b) | Sound environment pleasantness | Calmness perception | Vibrancy perception | Road traffic annoyance | Children noise annoyance | People shouting annoyance |
|---|---|---|---|---|---|---|---|---|
| Intensity of sound | x | x | | x | | x | | |
| Fluctuation | | | | | | | x | x |
| Sharpness | | | x | | | | | |
| Roughness | | | | | | | | |

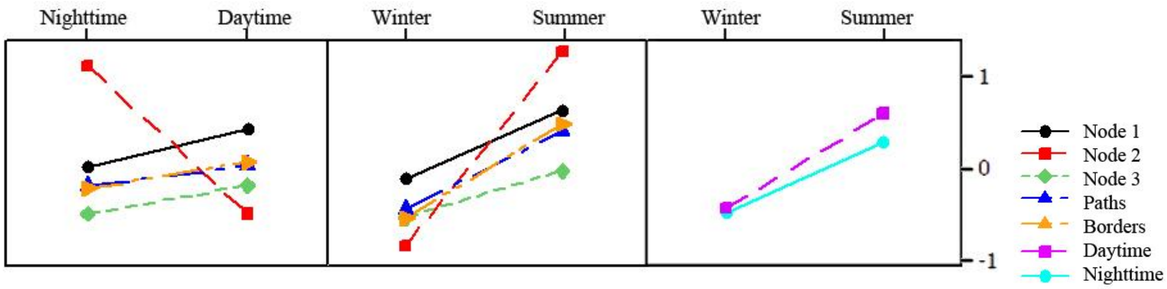
Figures 3(a-c) show the interaction plots related to some subjective and objective parameters, for the day/night and summer/winter periods, representing the differences among the investigated key-spaces. In particular the results referred to the six paths, the three nodes (n.1 market square, n.2 Saluzzo square and n.3 arcades) and the four edges (or borders).




(a) Light environment pleasantness




(b) Sound environment pleasantness




(c) Sharpness factor

**Figures 3 a-c:** The interaction plots show the differences among the investigated key-spacesrelated to some subjective and objective parameters, for the day/night and summer/winter periods.

As far as the light environment pleasantness is concerned the daytime condition, as expected, is preferred to the nighttime condition in each key-space, both in the summer and the winter period. The arcades score the lowest mark and the paths and Largo Saluzzo (a small quiet square) the highest.

The sound environment pleasantness presents differences for each key-space. An inverse correspondence has found between the sound pleasantness scores and the factor scores related to the sharpness in the daytime and nighttime periods. As suggested by literature (Zwicker & Fastl 1999) the sound environment pleasantness decreases with increasing the sharpness.

Largo Saluzzo (node n. 2), as expected, results the most pleasantness space related to sound environment, while the arcades the most unpleasantness (node n. 3).

## CONCLUSION

This paper presents some results related to the *livingscape* analysis in an urban open public space, based on in-field surveys during Summer 2010 and Winter 2011. Starting from a historical previous study thirteen key-spaces were selected, which characterize past and present soundscape of the district. These spaces were then subdivided in nodes, paths and edges (or borders).

Thirteen factors were singled out from the factorial analysis on environmental data collected *in situ* based on 33 objective parameters related to the sound, light and thermal scape; in particular four acoustical factors can be associated to four different sound aspects: "Intensity of the sound", Fluctuation", "Sharpness" and Roughness".

Significant correlations (p<0.01) among the four acoustical factors and the subjective items related to the sound environment perception and pleasantness were obtained. In particular "road traffic annoyance" results correlated with the acoustical factor no.1 representing the "intensity of sound" while, as expected, "children noise annoyance" and "people shouting annoyance" are correlated with the "fluctuation" factor.

The interaction plots related to some subjective scores and objective parameters, for the day/night and summer/winter periods, show some differences among the investigated key-spaces. Apart from some obvious results related to light environment pleasantness during daytime with respect to nighttime, the sound environment pleasantness decreases with increasing the sharpness. Largo Saluzzo, a small quiet square, results the most pleasantness space related to sound and light environments, while the arcades the most unpleasantness.

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# Influence of temporal structure of the sonic environment on annoyance

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## INTRODUCTION

The relationship between environmental noise exposure and annoyance has been well-investigated and well-documented, insofar that the European Commission includes estimated annoyance as an evaluation measure for the impact of noise exposure (2002-49-EC). Although exposure-effect relationships for different sources have been generally accepted, the uncertainty in these models remains substantial (Marquis-Favre et al. 2005; Fields et al. 2000) for example have calculated that the response between communities differs on average by the equivalent of about 7 dB in noise exposure. One major issue here is the contribution of non-acoustical factors (Fields 1993) and another the uncertainty of the exposure modeling method (Lercher et al. 2008b).

In addition, current exposure indicators are overall, average measures like $L_{den}$. Nevertheless, sound perception does not only depend on overall sound pressure levels, but also on the temporal structure of the sound and on subject's attention (Botteldooren et al. 2008; De Coensel et al. 2009). Because annoyance is related to perception, including those temporal aspects might improve noise annoyance models. It could be hypothesized that the established source dependence of reported annoyance (Miedema & Oudshoorn 2001) might be (partially) explained by differences in noise variation over time. In addition, people's activity patterns do not only introduce fluctuation in attention and—connected with this—noise perception, being at home or not also directly determines the A-weighted equivalent noise level people are exposed to in their home environment. In this, the negative effects of sleep-disturbance have been well-established (Miedema & Vos 2007), but noise exposure during awake periods could be equally important as it interferes with behavior (like communication and concentrated activity) or a desired state (like relaxation) (Miedema 2007).

Two major research topics are currently investigated, namely the possibility to capture the influence of the traffic noise source on annoyance by taking into account the temporal structure of the sound and the subject's attention, and possible model improvement by accounting for activity and time spend at home. Annoyance data are collected from a large-scale questionnaire conducted in North and South Tyrol. For each participant's dwelling, noise data are calculated using noise mapping and detailed traffic models. Additionally, the previously developed notice-event model (De Coensel et al. 2009) is applied, taking into account activity patterns from Austrian inhabitants and simulated sound pressure level time series.

## MATERIAL AND METHODS

### Reported annoyance

In 2004, a face-to-face survey was carried out in the framework of the BBT (Brenner Base Tunnel) study conducted in North and South Tyrol for 2,070 volunteers. More details about data collections can be found in Lercher et al. (2008a). Noise annoyance was measured on an 11-point scale (compliant with ICBEN and ISO standards) by asking (in German) 'How much are you annoyed/disturbed during the past 12 months in your home or on your property' separately for highway, main road and railway.

### Noise exposure

Estimating the time-varying sound level at the dwelling façade of each survey participant caused by transportation noise, ideally involves simulating the dynamic behavior of all vehicles/trains on the surrounding roads/tracks, coupled with a detailed modeling of sound propagation (De Coensel et al. 2005). For a large number of survey locations, this approach becomes unfeasible because of computational complexity. Instead, a simplified two-stage estimation procedure is followed here. Firstly, time series of values caused by each source at each survey location are simulated, taking into account the *closest* highway, major road and railway only. Simplifications are used for pass-by distributions, source strength and sound propagation (see De Coensel et al. 2009) for more details on this proceeding. Secondly, the simulated time series are calibrated such that the $L_{den}$ corresponds to that obtained from a noise map, taking into account the particular alpine propagation conditions of the study area (Heimann et al. 2007). In essence, the first stage makes sure that the temporal structure of the simulated level time series is realistic given the distance of the survey point to the roads/tracks, while the second stage fixes the overall level. Finally, percentile levels were calculated for the total sound exposure, as well as for the exposure caused by all combinations of sources, based on the calculated time series of values for each source.

From the percentiles, *'fluctuation'* and *'emergence'* can be calculated per source. The fluctuation is the difference between the source event ($L_1$ for highway, $L_5$ for main roads, $L_{10}$ for railway) and the source background level ($L_{90}$ for highway, $L_{99}$ for main roads, $L_{90}$ for railway). Emergence on the other hand is the difference between the source event ($L_{10}$ for highway, $L_5$ for main roads, $L_{10}$ for railway) and the overall background level consisting of the sound of all natural and traffic sources except the source under study ($L_{90}$ for highway, $L_{99}$ for main roads, $L_{90}$ for railway). For the three sources, particular percentile levels are selected to establish minimal correlation between fluctuation, emergences another noise measures, an important issue for statistical modeling later on.

### Notice event model

The simulated sound level time series serve as input to the notice-event model (De Coensel et al. 2009). This psychoacoustic model is used to estimate (on a statistical basis), for each dwelling in the survey, the time periods that a person, living at that dwelling, would pay attention to the sound of each of the considered sources. For this, a 'virtual' individual is modeled for each participant in the survey. Next to the temporal pattern of the signal-to-noise ratio of the sound of each source as compared to the other sources, the notice-event model takes into account effects of habituation to sound sources over time, and focusing of attention after sudden changes in levels. More details can be found in De Coensel et al. (2009). Essential is that the sound produced by each modeled individual itself (through its activity, such as cooking or watching television) has to be taken into account, including the location of the activity and the corresponding sound insulation of the dwelling. This is necessary since activity-related sounds may mask intruding transportation noise. In order to construct activity patterns for each survey participant, a number of personal variables are used, such as the age category, the type of employment, or whether the person works in shifts or works at night. Representative 14-day activity patterns for each combination of variables are extracted from the ALPNAP database of activity diaries collected from people living in an adjacent study area, in combination with the Austrian Time Use Survey of 2008-2009. Subsequently, an activity-related sound level time series was constructed for each activity pattern, based on sound level ranges found in literature (Diaz & Pedrero 2006). Finally, results of the notice-event model are only considered for those time periods for which the person is at home and not sleeping. A first outcome of the notice-event model is the (indoor) exposure $L_{Aeq}$ calculated over these 'home-and-awake' periods for each source. A second outcome is the estimate of the total duration of attention paid to each sound source, the notice time. Inspired by the hypothesis that only consciously noticed sounds contribute to annoyance, a third outcome is the notice SEL of the sound of each source during those periods that it is paid attention to. Additionally, assuming that the contribution of an event to annoyance is proportional to its audibility above the background, a fourth outcome is the noticed sound exposure level above the notice-threshold, noted as notice SELthr.

### Statistical analysis

Logistic regression is carried out with statistical software R to investigate probability of high annoyance in terms of noise exposure. For the outcome variable, noise annoyance questions for the three sources are grouped into one variable *annoyance* which is rated 'high' for answers between 8 and 10.

Not purely acoustical independent variables are the *noise source* (levels 'highway', 'main road' or 'railway') and the *distance* to that particular source. For the acoustical indicators per source, $L_{den}$, *fluctuation, emergence,* $L_{Aeq}$ *during home and awake periods, notice time, notice SEL* and *notice SELthr* are selected as candidate independent parameters. Per observation in the data set, reported annoyance is linked to noise from the particular source the question was referring to.

Candidate independent variables are introduced in the different models through a manual stepwise procedure. Conclusions on variables' contribution to the model are based on the statistical significance of their coefficients (α=0.05) and changes in model deviance and AIC (Akaike Information Criterion)—measures of a model's goodness-of-fit—when this variable is added. Finally, the goodness-of-fit is addressed with the le Cessie–van Houwelingen normal test statistics (p>0.05) and typical measures for the model's predictive power are calculated like C index– corresponding to the area under the ROC curve–, Somer's $D_{xy}$, Goodmann-Kruskal gamma, Kendall τ, Nagelkerke's $R^2$ and Brier score (Harrell 2001).

## RESULTS

### Sound source and time pattern

First, probability of high annoyance is modeled as a function of $L_{den}$ and sound source to set a benchmark. As expected, Figure 1 reveals that the probability of high annoyance increases with increasing $L_{den}$ ($p<0.001$). In this model, probability of high annoyance appears lower for railway noise than for road traffic noise ($p<0.001$), which is in accordance with previous studies investigating high annoyance as a function of source specific day-night levels (DNL) (Miedema & Vos 1998).

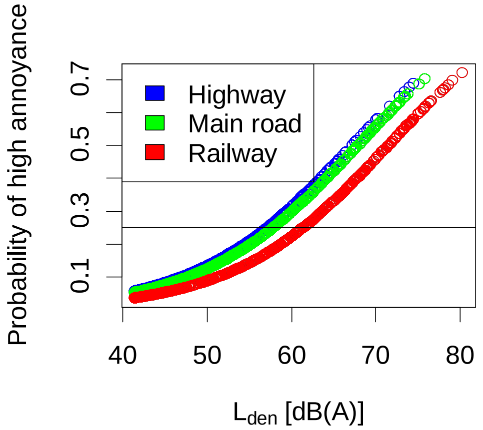


**Figure 1:** Probability of high annoyance from traffic noise as a function of $L_{den}$ and noise source. As a reference, 0.25 probability of high annoyance is indicated.

Secondly, high annoyance is investigated in relationship to $L_{den}$ and notice-event parameters *notice time, notice SEL* and/or *notice SELthr*, so without the noise source as such. This leads to the following expression for probability of high annoyance P(HA)

$$\mathbf{P(HA)} = \frac{\mathbf{1}}{1 + \exp(-X\beta)} \quad \mathbf{(1)}$$

$$X\beta = -5.8 + 0.06\,\mathbf{Lden} + \mathbf{7.4}\cdot\mathbf{10^{-6}}\,\tau + \mathbf{0.01}\,\varsigma \quad (2)$$

with τ notice time and ς notice SEL.

The new expression consumes 3 degrees of freedom like the previous model with the variable noise source, but it has a more favorable AIC (4,622.5 versus 4,653.1). In addition, the new model scores (slightly) better on predictive power although for both expressions the goodness-of-fit is less convincing ($p<0.001$). Nevertheless, this suggests that notice-event parameters are better in predicting annoyance for different sound sources than naming the source. An increase in $L_{den}$ has the strongest influence on increasing probability of high annoyance ($p<0.001$), followed by notice SEL ($p<0.001$) and notice time ($p<0.001$).

In Equation 2 *notice SEL* could be replaced by *notice SELthr* and although the latter variable contributes statistically significantly, the AIC is slightly worse (4633.2). Due to their extreme correlation (Pearson ρ =0.98), both variables could not be combined in one model.

Finally, adding the variable sound source to Equation 2 reveals that the sound source as such still has a statistical significant influence ($p<0.001$) similar to the baseline model, stronger than notice time but less important than $L_{den}$ and notice SEL. Hence, the time pattern of a particular noise source appears clearly important in the general appreciation of a source, but it cannot explain everything.

## An alternative parameter for $L_{den}$

Because the questionnaire addresses explicitly noise annoyance at home, indoor $L_{Aeq}$ during periods that people are actually at home an awake is put forward as an alternative exposure indicator. Statistically modeling the probability of high annoyance as a function of $L_{Aeq}$ during home and awake periods (see Figure 2) reveals that this model has a better AIC then the model with only $L_{den}$ (4,575.9 versus 4,676.3). Moreover, its predictive power appears better and the goodness-of-fit is satisfying ($p > 0.05$) whereas it is not the case for the expression with $L_{den}$ ($p<0.001$).

Comparing Figure 1 and Figure 2 reveals that 0.25 probability of high annoyance corresponds to exposure levels around 60 dBA for $L_{den}$ whereas the level is substantially lower for $L_{Aeq}$ during home and awake periods (less than 50 dBA).

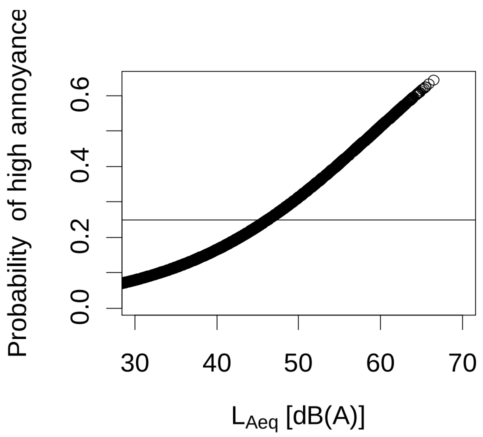


**Figure 2:** Probability of high annoyance from traffic noise as a function of $L_{Aeq}$ during home and awake periods. As a reference, 0.25 probability of high annoyance is indicated.

## Optimized model

The findings described in the two previous sections are combined into one model, analyzing the probability of high annoyance as a function of $L_{Aeq}$ during home and awake periods, notice time $\tau$ and notice SEL $\varsigma$. This leads to the following expression for $X\beta$ in the general equation 1

$$X\beta = -4.7 + 0.07\,\mathbf{LAeq} + \mathbf{8.3} \cdot \mathbf{10^{-6}}\,\tau + \mathbf{0.005}\,\varsigma. \quad (3)$$

Figure 3 illustrates that 0.25 probability of high annoyance for this model lies around the same level of $L_{Aeq}$ during home and awake when only that variable is taken into account (see Figure 2).

Similar to the model with $L_{den}$ (Equation 2), all independent variables contribute statistically significantly and $L_{Aeq}$ during home and awake periods appears the most influential parameter ($p<0.001$). However, notice time ($p<0.01$) is now slightly more important than notice SEL ($p<0.01$) and the AIC of the current model is better (4,574.5). This suggests that for the annoyance questions asked in this study, people base their response more on the noise they are exposed to when fully awake, and not on for instance possible sleep disturbance at night.

Furthermore, the performance of the current model is compared to a conceptually more elementary approach where the probability of high annoyance is assessed as a function of $L_{den}$, the sound source and the logarithm of the distance to the source. Comparing the AIC of both models confirms that taking into account notice-events and people's activity pattern really has an added value (4,574.5 versus 4,596.0). Moreover, its predictive power appears better and the goodness-of-fit is satisfying ($p > 0.05$) as opposed to the expression with distance and sound source ($p<0.001$). In addition, replacing in the current model the notice-event parameters by the noise source increase the AIC to 4,588.5, showing again the benefits of this new approach.

Finally, the possibility to improve the model in Equation 3 is further investigated by adding the variable *emergence, fluctuation* and *sound source* separately. Fluctuation has no statistically significant influence in this model, possibly because this variable is very strongly correlated to $L_{den}$ (Pearson $\rho$ =0.93). Similar, introducing emergence has only a limited effect ($0.05 < p < 0.1$) due to the high correlation with $L_{den}$ (Pearson $\rho$ =0.86) Third, the contribution of sound source is also marginally significant ($0.05 < p < 0.1$). Although no longer very pronounced, it should be noted that here railway noise has a higher probability of high annoyance (0.105) than main roads (0.09) and only slightly smaller than highways (0.112).

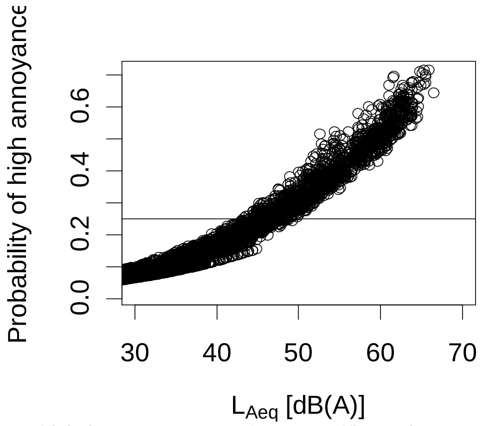


**Figure 3:** Probability of high annoyance from traffic noise as a function of $L_{Aeq}$ during home and awake periods, taking into account notice time and notice SEL. As a reference, 0.25 probability of high annoyance is indicated.

## DISCUSSION

Noise annoyance due to traffic noise is an important issue, especially given the increase in population density and mobility. In this regard, refined exposure-effect models might provide further insight and facilitate annoyance abatement.

$L_{den}$ is widely used as noise exposure indicator. This measure penalizes noise levels in the evening and at night because exposure is believed to be especially adverse when interfering with so-called restoration periods. However, in this analysis, noise annoyance can be predicted more precisely if $L_{Aeq}$ during home and awake periods is used instead of $L_{den}$, suggesting that nighttime noise exposure— when most people are asleep—determines less the reported annoyance. Naturally, this does not mean that noise-induced sleep disturbance could be regarded as less important, rather it might imply that people refer more to the actual disturbance during fully awake periods when answering the question on noise annoyance. A plausible explanation is that people adapt to nighttime noise exposure, decreasing subjective awakening (Passchier-Vermeer & Passchier 2000).

Another issue in noise exposure are the apparent differences between noise sources. This could be due to the temporal fluctuation of the particular sources, people's attitudes and believes towards them or, most likely, a combination of both (Miedema & Vos 1998). Current analysis suggests that the ability to notice sounds (operationalized by the the notice-event model) accounts to some extent for the difference in perceived annoyance between sources—at least more than entering only the noise source into the model. All three calculated parameters (notice time, notice SEL and notice SELthr) contribute significantly to the probability of high annoyance, but notice SELthr seems somewhat less capable of capturing the observed variance. A possible factor is the applied 'notice threshold' used to calculate notice SELthr. An improved estimation might increase the strength of the latter variable in estimating the probability of high annoyance.

All this underlines the importance of notice-ability, but this study does not allow to pronounce on a causal relationship between annoyance and temporal fluctuation. Moreover, the current analyses are not designed to make a strong point on the mutual relation of highway, main roads and railway with respect to (higher) risks of noise annoyance, all the more because highway and railway are tied closely together geographically in the data under study.

Further research should investigate the acoustical and non-acoustical variables that could be added to improve prediction of high annoyance. Here, (logistic) regression makes it sometimes difficult to assess the influence of candidate independent parameters because they are often more or less correlated. When non-acoustical parameters are further added to these notice event models it may be even more difficult to separate the various determinants of annoyance. More advanced modeling techniques might therefore be necessary in such extended models, also because they could provide more insight into the underlying mechanisms determining people's reaction to noise exposure.

## ACKNOWLEDGMENT

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# Variation of evaluation of signal sound in the public place with several kinds of noise

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## INTRODUCTION

Signal sound is used as a mark that indicates emergency or something important in the public place. It is expected that the signal can be easily heard and draw one's attention successfully. However, loud signal sound can cause annoyance. Therefore, signal sound in the public place should be planned appropriately. In the present research, one experiment is carried out to investigate the effects of frequency and sound pressure level with several kinds of noise on psychological evaluation of signal sound from the viewpoint of efficiency of drawing attention and annoyance.

## MEHODS

Ten persons (male = 9, female = 1) participated in the experiment. Pure tones of three frequencies (300; 800; 1,300 Hz) are used as signal sounds. Recorded noises at five kinds of sound environment and pink noise are used as back ground noise. $L_{Aeq}$ of recorded noises and pink noise are shown in Table 1.

**Table 1:** $L_{Aeq}$ of recorded noises and pink noise

| Noise No. | $L_{Aeq}$ [dB)] | kind of noise | included sound |
|---|---|---|---|
| 1 | 77 | inside a train | railway track noise, A/C noise, announcement, talking |
| 2 | 50 | pink noise | pink noise |
| 3 | 64 | shopping mall | talking, footsteps, A/C noise, BGM |
| 4 | 74 | street crossing | talking, footsteps, BGM, road traffic noise, cell phone, honker sound |
| 5 | 74 | station concourse | talking, footsteps, guide signal, road traffic noise, honker sound, ticket vender, cell phone |
| 6 | 79 | station platform | railway track noise, announcement, ringing bell, talking, footsteps |

Signal sound has time length of one second, and there are 4.5 seconds between one signal and the next. Three signal sounds constitute of one set of signal. Each signal sound that has two conditions of sound pressure level (64, 84 dBA) is added to each noise. In this way, 36 experimental sounds are created. Each subject experiences all of the experimental sounds through headphone.

### Evaluation method

After listening each experimental sound, subjects are asked about three types of questionnaire. Firstly, they are asked whether they can hear the signal sounds or not. Secondly, they are asked about impression of signal sound comparing to noise by five steps. Finally, they are asked about impression of whole sound environment that consists of signal and noise. Evaluation items are shown in Table 2 and 3.

**Table 2:** Evaluation items on the impression of signal sound

| No. | evaluation item | No. | evaluation item |
|---|---|---|---|
| A | easy to hear | G | loud |
| B | bothersome | H | easy to recognize |
| C | secure | I | high |
| D | comfortable | J | urgent |
| E | anxious | K | favorite |
| F | easy to attend to | L | good |

**Table 3:** Evaluation items on the whole impression of sound environment

| No. | evaluation item |
|---|---|
| M | annoying |
| N | noisy |

## RESULTS

### Audibility

No subject can hear signal sound of 300 Hz and 64 dBA under the noise condition of "inside of a train", "street crossing", and "station concourse". It is because succeeding noise that has large amount of low frequency masks the signal sound. Besides, no subject also can hear signal sound of 800 Hz and 64 dBA under "street crossing" noise condition.

### Impression of signal sound

In all noise conditions, there are similar evaluation tendency. Results show that higher and louder signal sound can easily draw subject's attention and be easily recognized. However, varieties of signal have few effects on secure feeling, comfort, or preference of signal sounds. Results are shown in Figure 1, 2, 3, 4, 5, and 6.

### Whole impression of sound environment

Figure 7 and 8 shows the results. They shows that sound environment that has signal of 1,300 Hz and 84 dBA is comparatively annoying and noisy. At the same time, sound environment with signal of 800 Hz is evaluated not so noisy.

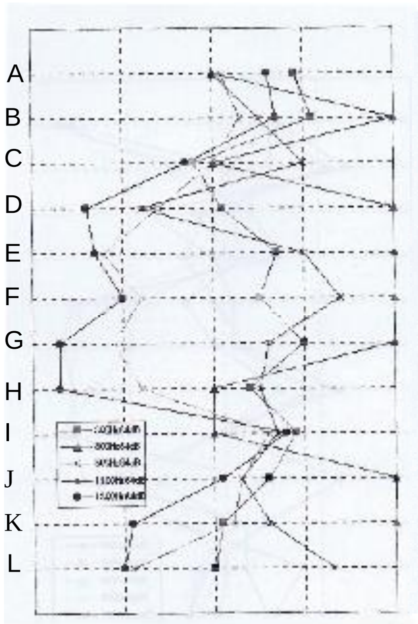


Figure 1: Noise No. 1

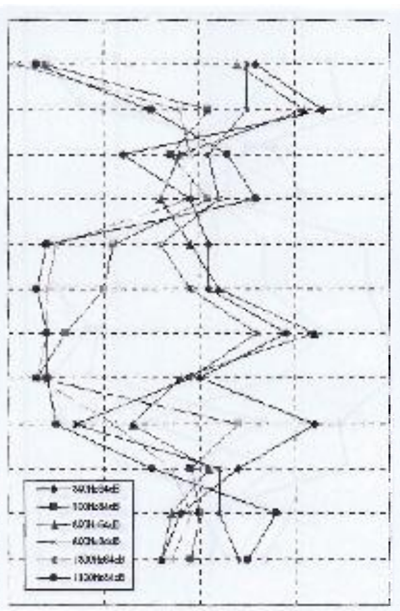

Figure 2: Noise No. 2

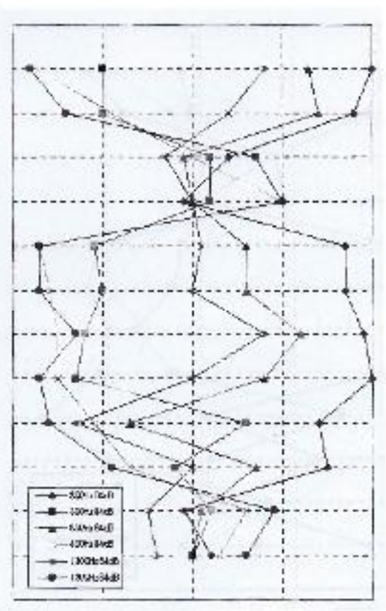

Figure 3: Noise No. 3

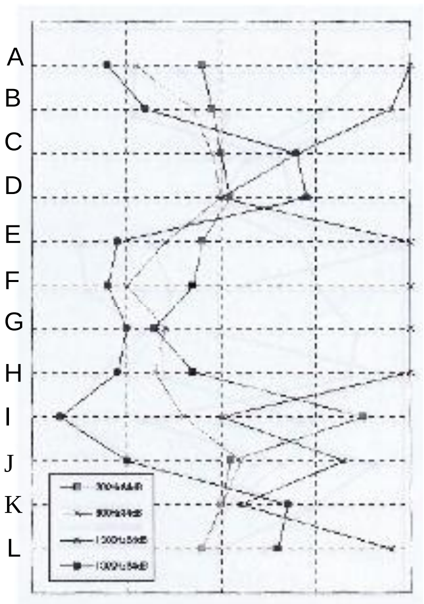


Figure 4: Noise No. 4

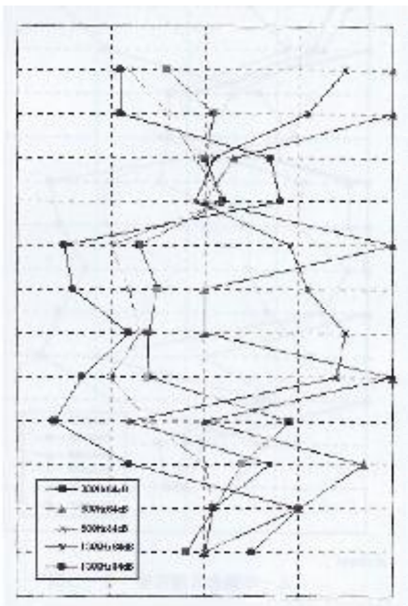

Figure 5: Noise No. 5

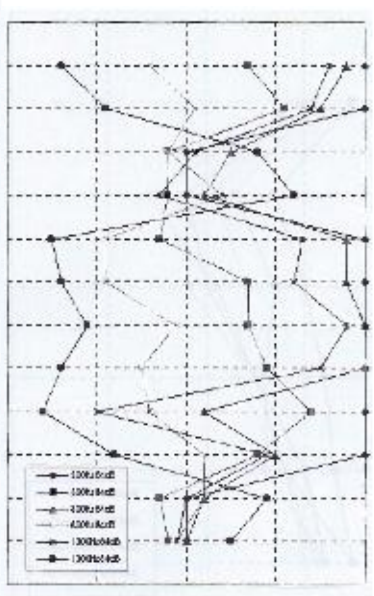

Figure 6: Noise No. 6

Vertical axis shows the evaluation items in Figure 1 to 6. Lateral axis shows the evaluation steps. Left side means "Yes" and right side means "No".

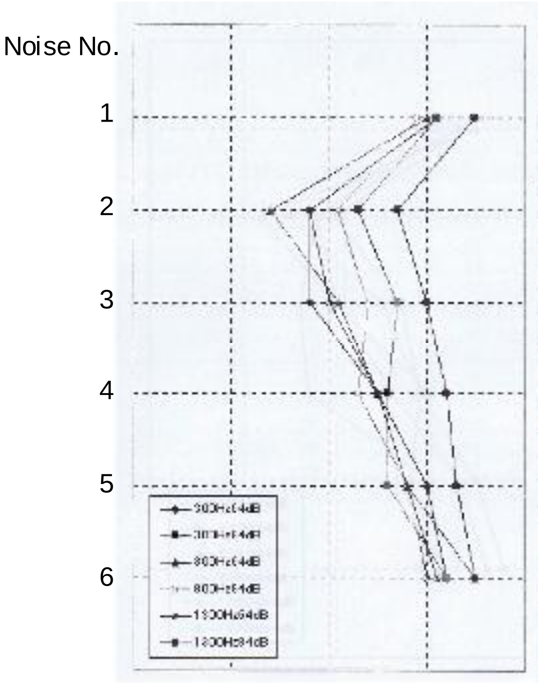


Figure 7: Annoying impression

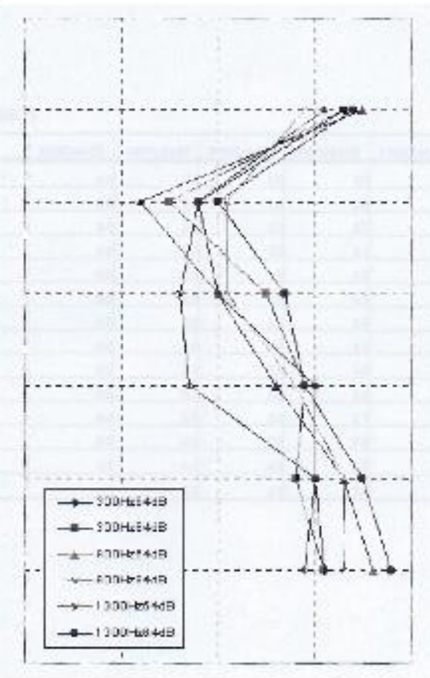

Figure 8: Noisy impression

Vertical axis shows noise conditions in Figure 7 and 8. Lateral axis shows annoying and noisy impression.

## CONCLUSIONS

It is suggested that signal sound of 1,300 Hz can easily draw person's attention, and louder signal can be recognized more easily. However, such recognizable signal sound can cause annoying and noisy feeling when it becomes a part of back ground noise. Signal sound should be designed as a recognizable mark for people who need the information, but it should not be noisy sound for people who do not need it. The present research indicates that signal sound may become noise in some situations. Moreover, results suggest that signal sound with frequency around 800 Hz has a good balance of noticeable and not so noisy impression in the public place.

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# Noise and health-related quality of life in people living near a motorway

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## INTRODUCTION

There is scientific evidence linking community noise to health problems (WHO 2009; Dratva et al. 2010; Kaltenbach et al. 2008). The WHO reports that chronic noise-induced annoyance and sleep disturbance can compromise health and health-related quality of life (HRQOL) (Berglund et al. 1999; Niemann & Maschke 2004; WHO 2009). However, there has been little research examining the relationship between noise and HRQOL. An exception is Dratva et al. (2010), who, using the Short Form (SF36) health survey, reported an inverse relationship between annoyance from traffic noise and HRQOL. They argued that HRQOL would be expected to co-vary more with annoyance than with noise level as level is a poor predictor of the human response to noise, and its role in health is commonly over-emphasized. As alternatives to noise level, other factors associated with the listener should be considered (Lercher, 1996), including the perceived control a person has over the noise, as well as their attitudes, personality, and age.

Noise sensitivity considered a stable personality trait that is relatively invariant across noise level (Zimmer & Ellermeier 1999), and is a strong predictor of noise annoyance (Pedersen & Waye 2008; Miedema & Vos 1999; Paunović et al. 2009). Stansfeld (1992) identifies two key characteristics of noise sensitive individuals. First, they are more likely to attend to sound and evaluate it negatively (e.g. threatening or annoying) and second, they have stronger emotional reactions to noise, and as a consequence, greater difficulty habituating. Noise sensitivity has a large impact on noise annoyance ratings, lowering annoyance thresholds by up to 10 dB (Miedema & Vos 1999). On the other hand, a ‘third variable’ hypothesis has been developed (Fhyri & Klaeboe 2009) suggesting that noise sensitivity does not moderate the effects of noise annoyance, but rather that it marks the presence of susceptibility to health problems and also to annoyance from noise.

Health may be assessed in terms of health related quality of life (HRQOL). The constituent domains of quality of life have different names depending on the measurement tool but they include physical health, psychological wellbeing, social relationships, and salient factors of the environment. HRQOL is normally assessed via a questionnaire. Each question in HRQOL questionnaires is selected on the basis that it discriminates between those who are sick and those who are well. Candidate questions with apparent relevance, or face validity, are used in the development of HRQOL scales; if they do not satisfy the discriminative criterion they are dropped from the final instrument. The World Health Organization developed its HRQOL measure (WHOQOL) in conjunction with 15 member states and it has now been adapted into use by over 50 countries globally. The full version is long, and for epidemiological purposes a short form (the WHOQOL-Bref) has been developed. This contains one item from each of the full WHOQOL's 24 facets, and allows respondents to be scored according to the four domains described above (WHO 1996).

Whether noise sensitivity causes poor health or whether it is a marker of susceptibility to health problems is an interesting question. By sampling from the populations in two types of area, close to and far from a motorway, we sought to provide evidence which would answer this question: if the people who lived in a relatively noise-free environment experienced similar associations between noise sensitivity and HRQOL as those living near a motorway, then noise sensitivity could be regarded as a marker, whereas if noise sensitivity is associated with poorer HRQOL in those near motorways, then it is moderating the response to noise.

## METHODS

Questionnaires were delivered to 1,250 households, 750 of which were within 50 m of one of three motorways in Auckland City, New Zealand, and 500 in socioeconomically matched (on the basis of household income) areas far from a motorway. Data from 502 adult respondents were returned: 257 from near motorways and 245 from control areas. These were analyzed to explore the relationship between traffic noise annoyance and health-related quality of life (HRQOL) as assessed by the WHOQOL-Bref.

## RESULTS

Of the 493 who responded to the question about noise sensitivity, 184 (37 %) were not sensitive, 253 (51 %) were moderately sensitive, and 56 (11 %) were very sensitive. These proportions did not differ between the people who lived close to motorways and those in the socioeconomically matched control areas that were not near motorways (chi-squared (2)=0.805, p=0.669). On the other hand, annoyance caused by traffic fumes and traffic noise were both higher in those who lived close to motorways than those who did not, while scores on the four WHOQOL domains were lower in those who lived near motorways (t-tests: all p<0.05; Figure 1).

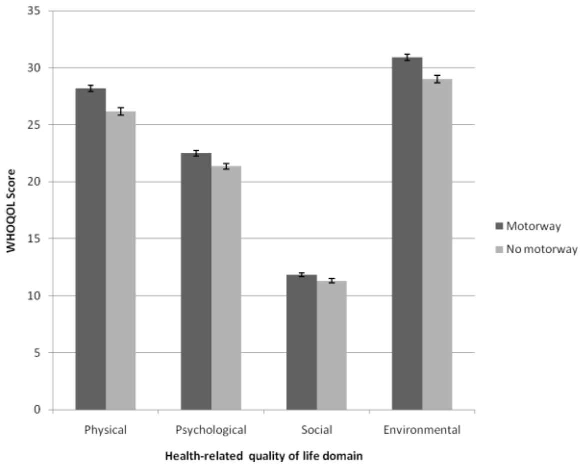


**Figure 1:** Mean WHOQOL domain scores for those living near and far from a motorway. Error bars represent on standard error of the mean

Annoyance caused by traffic fumes and annoyance caused by traffic noise were correlated overall (Spearman's Rho=0.499, p<0.001), implying that those who were more annoyed by traffic noise were also more likely to be annoyed by air pollution caused by traffic. The correlation was significantly stronger in the people who lived near motorways (Rho=0.540, p<0.001: 95% CI=0.447-0.621) than in those who did not (Rho=0.317, p<0.001: 95% CI=0.200-0.425).

There were independent correlations between the four WHOQOL domains and annoyance due to fumes and noise. Noise sensitivity was also correlated with the WHOQOL domains except for the Social Domain (Table 1). Overall, effect sizes were similar for annoyance due to fumes and noise but somewhat lower for noise sensitivity.

**Table 1:** Pearson correlations between WHOQOL Domain scores and annoyance due to traffic fumes and noise and noise sensitivity

| | | Noise sensitivity | Physical domain | Psychological domain | Social domain | Environmental domain |
|---|---|---|---|---|---|---|
| Fumes annoyance | Pearson Correlation | 0.199 | -0.235 | -0.190 | -0.113 | -0.265 |
| | p-value | 0.000 | 0.000 | 0.000 | 0.012 | 0.000 |
| | N | 492 | 501 | 501 | 500 | 501 |
| Noise annoyance | Pearson Correlation | 0.151 | -0.229 | -0.209 | -0.148 | -0.308 |
| | p-value | 0.001 | 0.000 | 0.000 | 0.001 | 0.000 |
| | N | 491 | 500 | 500 | 499 | 500 |
| Noise sensitivity | Pearson Correlation | | -0.200 | -0.163 | -0.041 | -0.083 |
| | p-value | | 0.000 | 0.000 | 0.362 | 0.066 |
| | N | | 493 | 493 | 492 | 493 |

The difference in correlations between annoyance due to fumes and noise, noise sensitivity, and HRQOL is clear in Tables 2 and 3. Since the associations are not present, or are much weaker, in those who are not near to a motorway, this may be seen as evidence of a causal association between annoyance and HRQOL. Noise sensitivity was also correlated (negatively) with physical, psychological, and environmental HRQOL in those who dwell near motorways, but uncorrelated in those who do not. This suggests that noise sensitivity will impair HRQOL only when much noise is present, and thus that it moderates the effect of noise annoyance.

**Table 2:** Pearson correlations between WHOQOL Domain scores and annoyance due to traffic fumes and noise and noise sensitivity in people who did not live near to motorways

| | | Noise sensitivity | Physical domain | Psychological domain | Social domain | Environmental domain |
|---|---|---|---|---|---|---|
| Fumes annoyance | Pearson Correlation | 0.161 | -0.133 | -0.076 | -0.032 | -0.116 |
| | p-value | 0.012 | 0.038 | 0.235 | 0.623 | 0.071 |
| | N | 241 | 245 | 245 | 245 | 245 |
| Noise annoyance | Pearson Correlation | 0.068 | -0.089 | -0.129 | -0.076 | -0.203 |
| | p-value | 0.290 | 0.164 | 0.044 | 0.237 | 0.001 |
| | N | 241 | 245 | 245 | 245 | 245 |
| Noise sensitivity | Pearson Correlation | 1 | -0.091 | -0.029 | 0.026 | 0.003 |
| | p-value | | 0.160 | 0.653 | 0.683 | 0.967 |
| | N | 241 | 241 | 241 | 241 | 241 |

**Table 3:** Pearson correlations between WHOQOL Domain scores and annoyance due to traffic fumes and noise and noise sensitivity in people who lived near to motorways

| | | Noise sensitivity | Physical domain | Psychological domain | Social domain | Environmental domain |
|---|---|---|---|---|---|---|
| Fumes annoyance | Pearson Correlation | 0.223 | -0.255 | -0.237 | -0.148 | -0.325 |
| | p-value | 0.000 | 0.000 | 0.000 | 0.018 | 0.000 |
| | N | 251 | 256 | 256 | 255 | 256 |
| Noise annoyance | Pearson Correlation | 0.202 | -0.217 | -0.195 | -0.153 | -0.293 |
| | p-value | 0.001 | 0.000 | 0.002 | 0.015 | 0.000 |
| | N | 250 | 255 | 255 | 254 | 255 |
| Noise sensitivity | Pearson Correlation | | -0.279 | -0.274 | -0.094 | -0.143 |
| | p-value | | 0.000 | 0.000 | 0.138 | 0.023 |
| | N | | 252 | 252 | 251 | 252 |

The final stage of analysis was to conduct factor analysis to investigate the relationship between annoyance with traffic fumes and noise, noise sensitivity, and the WHOQOL facets, or items, that make up the domains described above. This was done separately for those living near and not near to motorways, and it revealed different patterns for the two groups. In those who did not dwell near to motorways, the two traffic annoyance variables were loaded on one factor with noise sensitivity, but with none of the WHOQOL facets. Noise sensitivity also loaded positively on a factor with positive loadings from facets about living conditions, access to health services, and transport. This suggests that noise-sensitive people who do not dwell near to motorways are more likely to be satisfied with these aspects of their lives. On the other hand, in the group who dwelt near to a motorway, noise sensitivity was loaded on a factor with WHOQOL facets about inability to concentrate, lack of energy, inability to accept bodily appearance, and frequency of negative feelings (anxiety, depression etc). The traffic fumes and noise annoyance variables, on the other hand, were loaded with the facets about living conditions, access to health services, and transport, but in a negative direction, implying that people who are annoyed by traffic fumes and noise are less likely to be satisfied with those aspects of their lives. Thus, the factor analysis suggested that noise sensitivity relates in different ways to HRQOL depending upon whether a person is subjected to much noise at home: where the traffic noise levels are high, noise sensitivity is associated with negative emotionality and low energy, whereas in quieter areas it is associated with positivity about the living conditions.

## CONCLUSIONS

Mean noise sensitivity did not vary with proximity to a motorway.

The feeling of annoyance due to the noise and air pollution of traffic was greater in those who lived close to motorways.

Scores on all four WHOQOL domains were lower in those who lived close to motorways.

WHOQOL domain scores correlated more strongly and negatively with annoyance from traffic noise and fumes in those who lived near to motorways.

WHOQOL domain scores correlated negatively with noise sensitivity in those who lived near to motorways but not in those who lived far from motorways.

Factor analyses suggested that noise sensitive people who live near a motorway are more likely to have reduced concentration, lack of energy, poor body image, and negative emotionality, whereas this was not the case for noise sensitive people living far from motorways.

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# Aircraft noise and annoyance in the populations living near the Ciampino airport in Rome

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## INTRODUCTION

Airport traffic noise has been increasing in recent years in Ciampino (Rome) because of the large rise in low cost flights. Since 2000 passenger traffic has been rising from about 830,000 passengers in 2000 to about 5,300,000 passengers in 2007 (about 6,000 flights a month). This increase, mainly due to low-cost flights, has produced concerns in citizens and the health authorities were asked to evaluate the possible health effects due to residential proximity to the airport.

Several studies have shown that aircraft noise is associated with health effects (Babisch 2006; van Kempen et al. 2002), in particular with the increase in blood pressure and a higher frequency of cardiovascular disease, (Haralabidis et al. 2008; Rosenlund et al. 2001; Matsui et al. 2004; Eriksson et al. 2007). Evidence from the HYENA study (HYpertension and Exposure to Noise near Airports, (Jarup et al. 2008)), suggests that aircraft noise exposure increases the risk of hypertension and that night-time aircraft noise is associated with high blood pressure (Haralabidis et al. 2008). The HYENA results were confirmed by the SERA study (Studio sugli Effetti del Rumore Aeroportuale – Study on the Effect of Aircraft Noise), conducted among residents around the airport of Ciampino, which had indicated the presence of a strong association between exposure to aircraft noise and blood pressure (Ancona et al. 2010). Annoyance due to noise represents one of the most investigated outcomes in environmental epidemiology (Miedema & Vos 2003; Miedema 2004). The HYENA study analyzed annoyance during both day and night, considering 6 major European airports. The study showed clear exposure-response relationships between the noise level and the noise annoyance for both exposures (Babisch et al. 2009). In a recent study was demonstrated that annoyance of residents at a given aircraft noise exposure level increases over the years noise sensitivity influences general noise and aircraft noise annoyance (Schreckenberg et al. 2010), while background noise level is one of the important factors on the estimation of community annoyance from aircraft noise exposure (Lim et al. 2008).

The objective of this study was to evaluate the association between aircraft noise and annoyance in people living close to the Ciampino airport in Rome.

## METHODS

We studied a randomly selected sample of 1,200 subjects aged 45-70 years who have lived in the study area for at least 5 years. Noise annoyance due to aircraft and road traffic noise were assessed via a face-to-face interview using the 11-point ICBEN scale. Aircraft noise maps were defined (three noise levels, $L_{aeq,24h}$ <60, 60-65, and 65-75 dB) using the Integrated Noise Model proposed by the USA Federal Aviation Administration. We linked each participant's address to the aircraft noise contours using a Geographic Information System. As a proxy for road traffic noise, we calculated morning (outside the rush hour) traffic volume (number of vehicles per hour <100; 100-400; >400). Within the $L_{aeq,24h}$ <60 area we then divided residents in highly urbanized and in suburban based on the volume of traffic recorded. The effects of airport noise on annoyance were analyzed through regression models adjusted for personal characteristics and road traffic volume.

RESULTS

The SERA study participation rate was 50 %, resulting in a study population of 597 participants. Figure 1 shows the participants location on the study area in relation to the different levels of airport noise exposure.

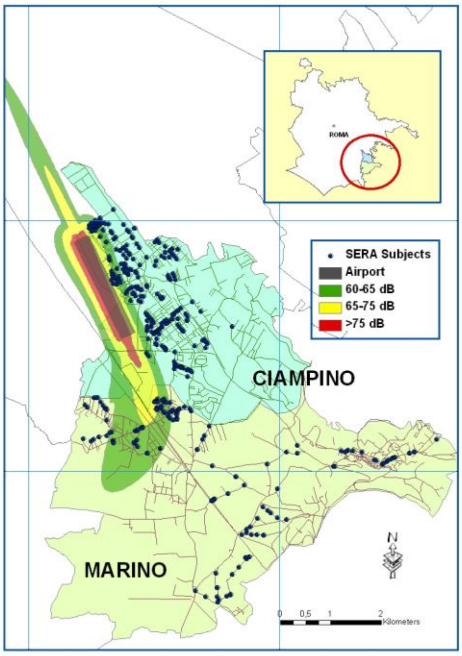


**Figure 1:** Location on the study area of the subjects in relation to the different levels of airport noise exposure

Table 1 shows the descriptive characteristics of the study population. The study sample (45 % females), had a mean age of 55.8 years (SD=7.3). About 13 % had a Body Mass Index defined by WHO as obesity, 26 % had a university degree, 53 % were currently employed (7 % has a job related to the airport). Regarding smoking habits, 25 % said they were current smokers while 39 % said they were ex-smokers. The most exposed group (53 persons resident close to the airport) was on average older than the reference group (216 persons resident far from the airport). People most exposed to noise were of normal weight (36 % vs 27 % of the reference), with university degree (26 % vs 20 %) and current smokers (28 % vs 21 %).

**Table 1:** Descriptive characteristics of the study SERA participants by airport noise impact

| | | Airport noise impact (dBA) | | | | |
|---|---|---|---|---|---|---|
| | | <60 Residential | <60 Urban | 60-65 | >65-75 | TOT |
| | | 216 | 219 | 109 | 53 | 597 |
| gender | males | 51.9 | 59.8 | 50.5 | 56.6 | 54.9 |
| | females | 48.2 | 40.2 | 49.5 | 43.4 | 45.1 |
| age groups | <50 | 25.0 | 24.2 | 29.4 | 22.6 | 25.3 |
| | 50-54 | 19.9 | 21.9 | 31.2 | 20.8 | 22.8 |
| | 55-59 | 21.3 | 19.6 | 20.2 | 15.1 | 19.9 |
| | 60-64 | 14.4 | 13.7 | 5.5 | 11.3 | 12.2 |
| | 65+ | 19.4 | 20.6 | 13.8 | 30.2 | 19.8 |
| mean age (SD) | | 56.3 (7.5) | 56.1 (7.0) | 53.9 (6.8) | 57.3 (7.9) | 55.8 (7.3) |
| Body Mass Index | < 25 (underweight -normal weight) | 27.0 | 34.7 | 35.2 | 35.9 | 32.1 |
| | 25-30 (overweight) | 58.6 | 56.2 | 47.2 | 52.8 | 55.1 |
| | >30 (obesity) | 14.4 | 9.1 | 17.6 | 11.3 | 12.8 |
| education (years) | <6 | 13.9 | 11.4 | 8.3 | 11.3 | 11.7 |
| | 6-9 | 22.7 | 17.8 | 19.3 | 32.1 | 21.1 |
| | 9-14 | 43.5 | 42.0 | 40.4 | 30.2 | 41.2 |
| | >14 | 19.9 | 28.8 | 32.1 | 26.4 | 26.0 |
| job | no/housewife | 17.1 | 11.5 | 16.7 | 17.3 | 15.0 |
| | retired | 34.3 | 33.5 | 24.1 | 36.5 | 32.3 |
| | yes | 48.6 | 55.1 | 59.3 | 46.2 | 52.7 |
| job related to Ciampino Airport | yes | 5.1 | 6.4 | 11.0 | 5.7 | 6.7 |
| smoke | never | 42.1 | 36.5 | 33.9 | 49.1 | 39.2 |
| | ex | 36.6 | 38.8 | 37.6 | 22.6 | 36.4 |
| | current | 21.3 | 24.7 | 28.4 | 28.3 | 24.5 |

Prevalence rates of annoyance from aircraft noise were lower among residents in quite areas (24 and 18 % day and night) than among those primarily exposed to airport noise (64 % and 47 % day and night) (Table 2).

**Table 2:** Percentage of subjects highly annoyed by aircraft and traffic noise during day and night by airport noise impact

| | | | Airport noise impact (dBA) | | | | |
|---|---|---|---|---|---|---|---|
| | | | <60 Residential | <60 Urban | 60-65 | >65-75 | TOT |
| | | | 216 | 219 | 109 | 53 | 597 |
| % highly annoyed | day | aircraft | 24.1 | 27.9 | 55.1 | 64.2 | 34.7 |
| | | traffic | 5.6 | 25.1 | 7.3 | 3.8 | 12.9 |
| | night | aircraft | 18.5 | 24.2 | 32.1 | 47.2 | 25.6 |
| | | traffic | 6.0 | 12.8 | 2.8 | 1.9 | 7.5 |

Multivariate analysis results showed that the proportion of people very annoyed during the day increased with the level of airport noise exposure. After adjusting for sex, age, education, job and road traffic, and comparing with the reference group, we observed a RR of 1.35 in the exposed to <60 dBA, 2.19 in the exposed to 60-65 dBA, and 2.52 in the exposed 65-75 dBA. The same relationship was observed for people who said they were very annoyed by aircraft noise at night.

## CONCLUSIONS

The SERA study results confirmed those of other studies conducted in populations living near airports in Europe, indicating the presence of a strong association between exposure to aircraft noise and annoyance. The association that we found is somehow stronger than what has been indicated in previous studies.

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# Effect of the co-exposure to organophosphate pesticides and noise on the auditory function of farm workers

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## INTRODUCTION

On a daily basis, farmers use mobile and fixed machinery generating noise levels from 85 to 120 dBA (EU-OSHA 2008; Health and Safety Executive 2009). Therefore, it is not surprising that noise-induced hearing loss is common among farmers (Plakke & Dare 1992; Hwang et al. 2001; McBride et al. 2003). However, noise is rarely the sole contaminant in most work settings (Campo et al. 2009). Studies have demonstrated that concomitant exposure to noise and a variety of chemicals (solvents, asphyxiants, heavy metals, pesticides) increases the risk and/or severity of acquiring hearing loss (Campo et al. 2009; Johnson & Morata 2010; Vyskocil et al. 2011). Furthermore, organic solvents can by themselves produce otoneurotoxic effects in both humans and experimental animals (Vyskocil et al. 2009). Farmers use a variety of pesticides, among other methods, to manage pests. Organophosphate insecticides (OPs) are widely used worldwide in agriculture and horticulture because of their efficacy and rapid degradation (Maroni et al. 2000). Within this category of pesticides, frequently encountered active ingredients are malathion, chlorpyrifos, terbufos, diazinon and parathion-methyl (U.S. EPA 2004). OPs are known neurotoxic substances (Hawkers et al. 1989). They exert their neurotoxic action through the inhibition of nervous system acetylcholinesterases (AChE), enzymes responsible for the degradation of acetylcholine (ACh) at nerve junctions (Koelle 1994; Sidell 1994).

In the auditory system, the olivocochlear bundle (OCB) is mostly cholinergic and projects from the superior olivary complex (SOC, medial-MSOC, lateral-LSOC) in the brainstem to the hair cells (outer-OHC & inner-IHC) in the cochlea (Figure 1). ACh release from the olivocochlear terminals leads to a hyperpolarization of the outer hair cells (Cooper & Guinan 2006). The hyperpolarized outer hair cells elongate which in turn reduces the cochlear sensitivity (Guinan 1996; Lustig 2006). According to animal and human studies, this mechanism seems to improve signal detection in noise (Cooper & Guinan 2006). Under OPs intoxication, ACh accumulates in the synaptic space due to the inhibition of AChE, altering the transmission of action potentials from the OCB to the outer hair cells (Morata & Keith 2007). Outer hair cells are also more vulnerable to noise exposure and, in the case of a combined exposure with OPs, an interaction of effect could be expected.

Only a few human and animal studies have looked at the effect of OPs on the auditory function (Beckett et al. 2000; Teixeira et al. 2002, 2003; Beckett et al. 2004; Hoshino et al. 2008; Mac Crawford et al. 2008). Beckett et al. (2000) surveyed 185 farmers on pesticide exposure. According to these authors, 48.6 % of the farmers showed a high frequency hearing loss (measure by pure-tone audiometry) that might be related to the use of pesticides in the year prior to the study. However, noise exposure was not documented, which could explain the prevalence of hearing loss in this cohort. In a follow-up study conducted with a small subgroup of the same farmers, Beckett et al. (2004) were not able to replicate their findings. Teixeira et al. (2002) examined central auditory processing in a group of 98 Brazilian workers exposed to noise and OPs as compared to a non-exposed control group (n=54). Both groups were stratified according to noise exposure level (interview). Pitch-pattern and Duration-pattern tests were administered. Results revealed that 56 % of the OP-exposed subjects showed abnormal performance on these tests compared to 7 % in the control group ($\chi^2$ = 32.77; p<0.001). In addition, workers with a longer duration of OP exposure (>6 years) showed a larger proportion of abnormal performance ($\chi^2$ = 8.46; p<0.004). The results were similar across noise exposed subgroups. In 2003, the same authors reported audiometric data for the same workers. Results showed a greater proportion of hearing loss (> 25 dBHL) in the workers exposed to OPs for more than 6 years (71.4 vs 57.1 %); the severity of the hearing loss and the impaired frequency range were also more important for the workers exposed to both noise and OPs as compared to workers exposed only to noise. However, none of these differences were statistically significant. More recently, Hoshino et al. (2008) examined 18 Brazilian workers exposed to OPs and found a prevalence rate of 39 % of high frequency hearing loss and abnormal peripheral vestibular function in 89 % of the workers. This study did not include a control group. As in all cited studies, exposure data for OPs were obtained using a questionnaire and no specific measures were taken. Mac Crawford et al. (2008) looked at self-reported hearing loss and pesticide exposure (including OPs) in a cohort of 14,229 American white male. Compared with controls, the odds ratio for hearing loss with OPs exposure was 1.17 [95IC: 1.03-1.31] after controlling for age, smoking, noise, solvents, and metals. All the studies reviewed here have serious limitations: lack of exposure data for OPs and/or noise, use of audiometric measures that are not sensitive to OP mode of action on the hearing system, absence of control group. Therefore, no clear evidence of an ototoxic effect for OPs can be drawn.

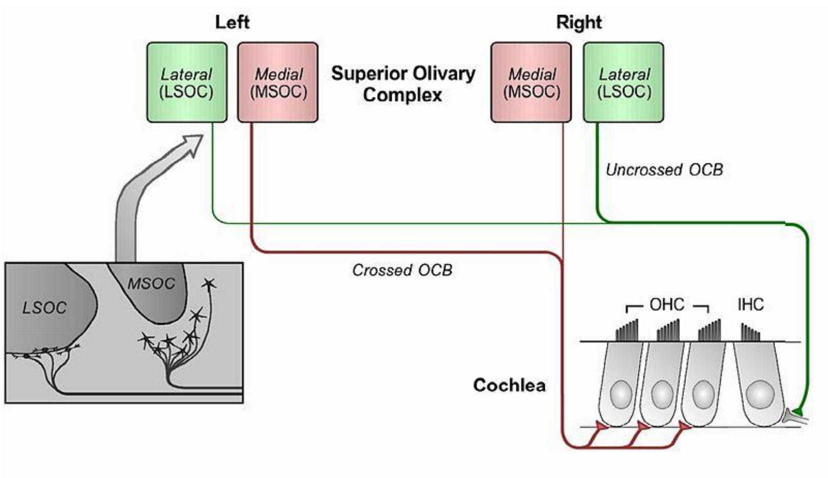


**Figure 1**: The mammalian olivocochlear bundle (Tan 2009)

The present study examines the effect of noise exposure and contamination by OPs on the auditory function of farm workers using standard audiometric measures and tests sensitive to dysfunctions of the efferent auditory system.

## METHODS

Experimental subjects were farm workers exposed for at least 2 years to malathion, chlorpyrifos, diazinon, azinphos-methyl, phosmet or phosalone. Subjects suffering from hypertension, renal or hepatic problems, presenting alcohol or drug abuse, using ototoxic medications, exposed to solvents or heavy metals were excluded. The study group consisted of 5 workers exposed to OPs and noise, 8 noise-exposed workers, and 12 non-exposed workers for a total of 25 subjects. Subjects' characteristics are summarized in Table 1.

**Table 1:** Sampling description for experimental and control groups

| Groups | Group 1 OPs + Noise | Group 2 Noise only | Group 3 Controls | Total |
|---|---|---|---|---|
| Sample size | 5 | 8 | 12 | 25 |
| Women | 1 | 4 | 6 | 11 |
| Men | 4 | 4 | 6 | 14 |
| Mean age (± sd) | 46.4 ± 11.4 | 53.3 ± 12.4 | 45.0 ± 15.9 | 47.9 ± 13.4 |
| Weight (kg) | 77.8 ± 14.3 | 76.5 ± 16.0 | 72.9 ± 17.1 | |
| Height (m) | 1.74 ± 0.06 | 1.68 ± 0.12 | 1.72 ± 0.1 | |
| Use of tobacco | 20 % | 25 % | 16.7 % | |

Data on medical and work history, noise and pesticides exposure in career, and life habits were collected through standardized questionnaires. Auditory functions were assessed in a sound-proof booth using audiometric thresholds for conventional (0.25 to 8 kHz) and very high frequencies (9 to 16 kHz), distorsion product otoacoustic emissions (DPOAEs) [parameters: $f_1/f_2$ de 1,22; $L_1$=65 dB SPL; $L_1$-$L_2$=10 dB SPL; 7 frequencies between 1 and 8 kHz; n=3 averages], contralateral suppression of transiently evoked otoacoustic emissions (TEOAEs) [parameters: click stimulus 60 dBSPL insitu, contralateral noise level 60 dBSPL, n=500 averages], acoustic reflexes thresholds and masking level difference (MLD) [parameters: $S_oN_o$, $S_\pi N_o$ and $S_oN_\pi$]. Normative criteria were applied to MLD data (Lynn et al. 1981) and to contralateral suppression (Berlin et al. 1993). Data were collected shortly after OP exposure (<24 h) and at least after 14 h without any noise exposure. Urine was collected in two 12-h periods, before and after exposure to OP; specific and nonspecific biomarkers of exposure to various OPs were measured (not reported in this paper). Numerical variables were studied by analysis of covariance for repeated measures variables (rANCOVAs $p<0.05$) with two within subject factors (ear, frequency), one between subject factor (group) and a covariable (age). Categorical variables were compared with chi-square (corrected $p<0.025$ for non-normal distribution). For statistical analysis, all means were adjusted for age to account for this confounding variable.

## RESULTS

Table 2 shows the characteristics of OPs exposure for Group 1. The workers have been exposed to four different OPs, and none have been exposed to chlorpyrifos. The mean duration of exposure was of 132 ± 100 min and consisted of treated plants manipulation in all cases except one where one worker sprayed OPs during data collection.

**Table 2:** Summary of OPs exposure characteristics for Group 1 (n=5)

| Characteristics of OPs exposure | | Number of subjects (Proportion) |
|---|---|---|
| **Specific OP** | | |
| Azinphos-methyl (guthion) | | 1 (20 %) |
| Chlorpyrifos | | 0 |
| Malathion | | 1 (20 %) |
| Phosalone (zolone) | | 2 (40 %) |
| Phosmet (imidan) | | 3 (60 %) |
| **Duration of exposure** (min) | Mean | 132 ± 100 [range: 30-240] |
| **Period of exposure before collection of data** | | |
| Last 24 h | | 5 (100 %) |
| The day before | | 4 (80 %) |
| Two days before | | 3 (60 %) |
| Three days before | | 5 (100 %) |
| **Tasks involving OPs** | | |
| Manipulation of treated plants | | 4 (80 %) |
| OPs spraying | | 1 (20 %) |

Figure 2 shows the age-adjusted audiometric threshold mean for the 3 groups. The analysis revealed that workers exposed to OPs and noise showed worst hearing thresholds between 4 to 9 kHz, but only 8 kHz reached statistical significance [$F_{(2,21)}$ = 5.137, p = 0.015]. Noise-exposed subjects were showing a smaller hearing loss restricted to 3 to 6 kHz. Audiometric thresholds obtained from noise-exposed and control subjects were not statistically different.

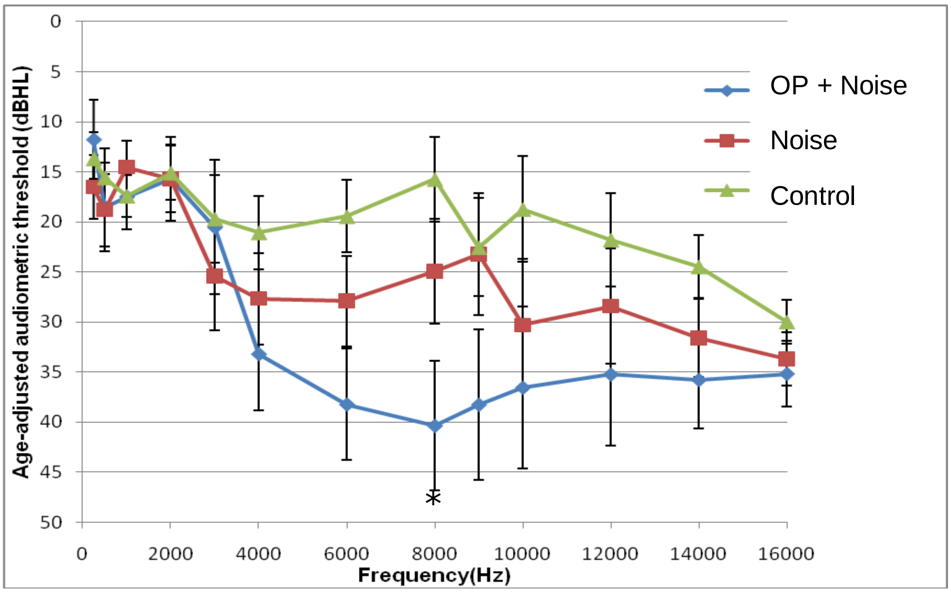


**Figure 2**: Group mean age-adjusted audiometric threshold

Figure 3 shows the age-adjusted DPOAE signal-to-noise ratio (SNR) mean for the 3 groups. The analysis revealed that workers exposed to OPs and noise showed smaller SNR for frequencies between 4 and 8 kHz. However, the observed differences did not reach statistical significance at any frequency [$F_{(2,21)}$ = 2.327, p = 0.121] because of weak statistical power (24 %) due to small sample size. Noise exposed and control group showed no difference.

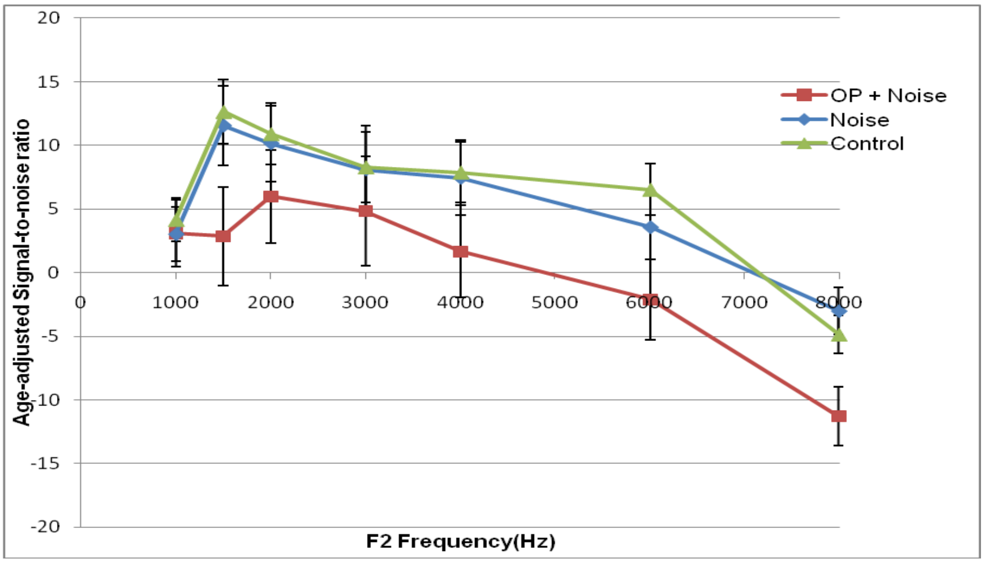


**Figure 3**: Group mean age-adjusted DPOAE signal-to-noise ratio

Table 3 shows the results obtained with measures sensitive to efferent system dysfunction (MLD, acoustic reflexes and contralateral suppression of TEOAEs). None of these measures showed any significant difference between OPs+noise and noise-only groups. The only significant differences were identified between controls and both experimental groups for MLD-$S_{\pi}N_o$ [$\chi^2_{2df}$ = 7.456, p = 0.024*] and MLD-$S_oN_{\pi}$ [$\chi^2_{2df}$ = 9.747, p = 0.008**]. For contralateral suppression of TEAOEs, the proportion of abnormal responses was higher in the OP and noise group as compared to noise and control groups. The larger differences were noted for 1.4 and 2 kHz but failed to reach statistical significance [$\chi^2_{4df}$ = 2.625, p = 0.622].

**Table 3:** Summary of results for MLD, Acoustic reflexes and Contralateral suppression of TEOAE

| **MLD - Abnormal response (%)** | | | | | |
|---|---|---|---|---|---|
| **Group** | | **SoNo-SπNo** | | **SoNo-SoNπ** | |
| **OP + Noise (n=5)** | | 40 | | 40 | |
| **Noise (n=8)** | | 50 | | 63 | |
| **Controls (n=12)** | | 0* | | 0** | |
| **Acoustic reflexes threshold - Mean ± SD (dB SPL)** | | | | | |
| **Frequency** | **Group** | **Ipsilateral** | | **Contralateral** | |
| | | **Left Ear** | **Right Ear** | **Left Ear** | **Right Ear** |
| **500 Hz** | **OP + Noise** | 98.0 ± 8.4 | 95.0 ± 11.2 | 97.0 ± 13.0 | 92.0 ± 11.5 |
| | **Noise** | 99.4 ± 9.0 | 98.8 ± 6.9 | 102.6 ± 6.5 | 101.9 ± 7.5 |
| | **Controls** | 91.7 ± 6.5 | 92.1 ± 6.2 | 96.7 ± 9.8 | 96.3 ± 10.0 |
| **1000 Hz** | **OP + Noise** | 94.0 ± 6.5 | 92.0 ± 9.1 | 90.0 ± 11.7 | 92.0 ± 10.4 |
| | **Noise** | 93.1 ± 7.0 | 94.4 ± 7.3 | 95.6 ± 7.8 | 95.6 ± 9.4 |
| | **Controls** | 89.6 ± 5.0 | 90.4 ± 6.2 | 89.6 ± 6.2 | 88.3 ± 6.5 |
| **2000 Hz** | **OP + Noise** | 96.0 ± 10.8 | 97.0 ± 9.1 | 90.0 ± 12.7 | 93.0 ± 11.0 |
| | **Noise** | 95.0 ± 9.3 | 94.4 ± 8.2 | 97.5 ± 8.0 | 94.4 ± 10.2 |
| | **Controls** | 92.1 ± 5.4 | 91.7 ± 6.9 | 90.0 ± 5.2 | 89.6 ± 5.8 |

**Table 3 cont.**: Summary of results for MLD, contralateral suppression of TEOAE

| Contralateral suppression TEOAE - Abnormal response (%) | | | |
|---|---|---|---|
| **Frequency** | **Group** | **Left Ear** | **Right Ear** |
| **1 kHz** | **OP + Noise** | 80 | 60 |
| | **Noise** | 75 | 75 |
| | **Controls** | 50 | 50 |
| **1.4 kHz** | **OP + Noise** | 80 | 80 |
| | **Noise** | 38 | 50 |
| | **Controls** | 50 | 33 |
| **2 kHz** | **OP + Noise** | 60 | 80 |
| | **Noise** | 25 | 38 |
| | **Controls** | 50 | 33 |
| **2.4 kHz** | **OP + Noise** | 80 | 80 |
| | **Noise** | 63 | 75 |
| | **Controls** | 75 | 76 |
| **4 kHz** | **OP + Noise** | 80 | 80 |
| | **Noise** | 63 | 63 |
| | **Controls** | 75 | 83 |

## CONCLUSIONS

Our results suggest that a combined OP and noise exposure might adversely affect high frequency hearing in farm workers. Audiograms obtained from workers exposed to noise only showed a more restricted hearing loss in the 3-6 kHz range as predicted by epidemiological database (ISO-1999 1990). Workers exposed to both contaminants showed a significantly more pronounced hearing loss at 8 kHz and worst hearing threshold for a larger frequency range between 4 and 9 kHz. Similar results were reported by Teixeira et al. (2003) for workers exposed to OPs for more than 6 years. DPOAEs signal-to-noise ratio (SNR) were reduced in the same frequency range between 4 and 8 kHz in the OPs and noise group. Animal studies by Job et al. (2007) and Carpentier et al. (2010) demonstrated a reversible DPOAE amplitude decrease after soman administration, clearly showing the sensitivity of this test to OP intoxication. However, the fact that no difference in DPOAE SNR was detected between noise-exposed and control groups is certainly not in agreement with previous studies that have clearly demonstrated that DPOAEs are sensitive to noise-induced hearing loss (Arnold et al. 1999) and to noise-induced outer hair cell dysfunction (Robinette & Glattke 2007). In this study we used a questionnaire to assess subjects noise exposure for their whole career. The absence of specific level of noise exposure, using field measurement data, has probably led to imprecise stratification as low and high exposure are pooled together. This limitation might explain why no DPOAE difference was identified.

Results of three tests sensitive to efferent system dysfunction failed to identify significant differences between OPs and noise group as compared to noise exposed and control groups. A tendency for a larger proportion of abnormal results in the contralateral suppression of TEOAEs was observed in the OPs and noise group for 1.4 and 2 kHz. Bernardi (2000) reported similar results for workers exposed to toluene and noise when compared to workers exposed to noise only and to control subjects. However, the difference observed in our study did not reach statistical significance, which might be attributable to the weak statistical power due to our small sample size. These preliminary results need further confirmation using a larger sample size but, at this time, a possible effect of OPs on both cochlear function and olivocochlear efferent system cannot be ruled out.

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# Subjective responses to noise levels in inpatient hospital wards

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## INTRODUCTION

Over the past 40 years there has been a growing body of research into the acoustic environment in hospitals providing evidence of the detrimental effects of noise on patient and staff well-being (Fife & Rappaport 1976; Topf & Dillon 1988), and of a significant rise in hospital noise levels (Busch-Vishinac et al. 2005). However, most of the evidence concerning the impact of noise has focused on specialist areas of care, with relatively little research into noise levels and acoustic conditions in general inpatient hospital wards, particularly in the UK.

The current study therefore aims to address some of the gaps in knowledge in the area of inpatient care, in order to provide better understanding of the importance of the acoustic design of hospitals, and its relationship with the comfort and well-being of staff and patients. A series of questionnaire, noise and acoustic surveys have been carried out in a range of wards in three major UK hospitals.

This paper will present the preliminary findings of questionnaire surveys completed by staff and patients in a surgical and medical ward at one of the three study hospitals. The responses provide insight into the causes of noise annoyance and disturbance, and highlight the differences between patient and staff perceptions and between different types of ward.

## THE QUESTIONNAIRE STUDY

Questionnaires were designed and piloted to assess the perceptions of staff and patients regarding the general noise environment, annoyance and disturbance caused by noise and the noise sources that cause most annoyance or disturbance. The two wards involved in the current study were located in the same five story hospital ward block and were identical in terms of layout, internal finishes and construction. Bed numbers were similar with 30 and 26 beds on the medical and surgical wards respectively. Patient accommodation was generally within a four or six bed bay, with four single rooms on each ward. The type of care offered and patient gender were the main differences between the wards, the medical ward specializing in care of the elderly and treatment of infections relating to gastroenterology, and the surgical ward offering elective orthopedic procedures. Patient accommodation in the medical ward was predominantly male with a single bay set aside for female patients; the opposite was the case in the surgical ward.

Staff and patients in both wards were asked to complete questionnaire surveys. With the help of the ward clerks, questionnaires were distributed to those patients who had been on the ward for over 24 hours and were judged to be physically and mentally fit enough to complete the survey. In total 40 patients completed the questionnaire in the medical ward and 42 in the surgical. Staff response was good in the medical ward with 18 questionnaires completed, but response in the surgical ward was rather poor, with only 7 staff completing the survey.

In parallel with the questionnaire surveys, acoustic surveys have been carried out in the same wards.

STAFF PERCEPTIONS

The staff questionnaire was designed to look specifically at noise annoyance and noise interference with the ability to work effectively.

### Noise annoyance

General feelings of annoyance were investigated by asking staff to what extent they were annoyed by noise. Figure 1 shows that the highest percentage of staff in the medical ward were moderately annoyed by noise (43 %), but this was not the case in the surgical ward, where the majority (56 %) of those questioned felt only slightly annoyed by noise.

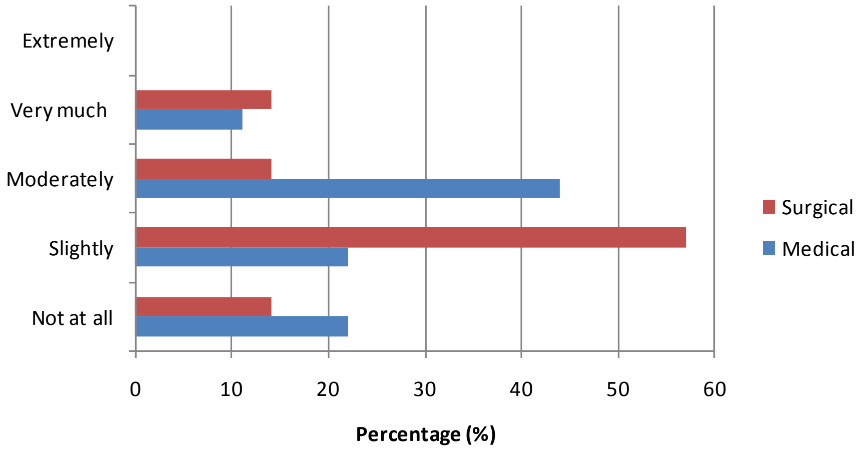


**Figure 1:** Percentages of staff annoyed by noise

Staff were asked to rate the annoyance of various noise sources (identified from the objective study) on a scale of 0 to 4, with 0 indicating 'not at all annoying' and 4 indicating 'a great deal'. Figure 2 shows the percentages of staff who rated a noise event with a 2, 3 or 4, and therefore could be said to be more than a little annoyed by the event.

It can be seen that the most annoying noise events for the staff on the medical ward were visiting time, medical equipment alarms and the internal telephone. This is similar for the surgical ward, except that there the nurse call is also rated by a high percentage of respondents.

Discrepancies of 20-30 % can be seen between the medical and surgical ratings for cleaning, people talking and staff talking. These events were found to be annoying by staff on the medical ward, but to a much less extent in the surgical ward.

Doors banging and external noise are rated more highly in the surgical ward. There is a particular heavy, ill-fitting fire door at the end of this ward that was mentioned during initial discussions with the ward manager. When this door bangs shut the noise travels down the full length of the ward corridor. With regards to the external noise, the surgical ward was surveyed during the summer months when the weather was warmer, whereas the medical ward was surveyed in the spring. This may account for the difference in external noise annoyance, as more windows may have been open in the warmer weather.

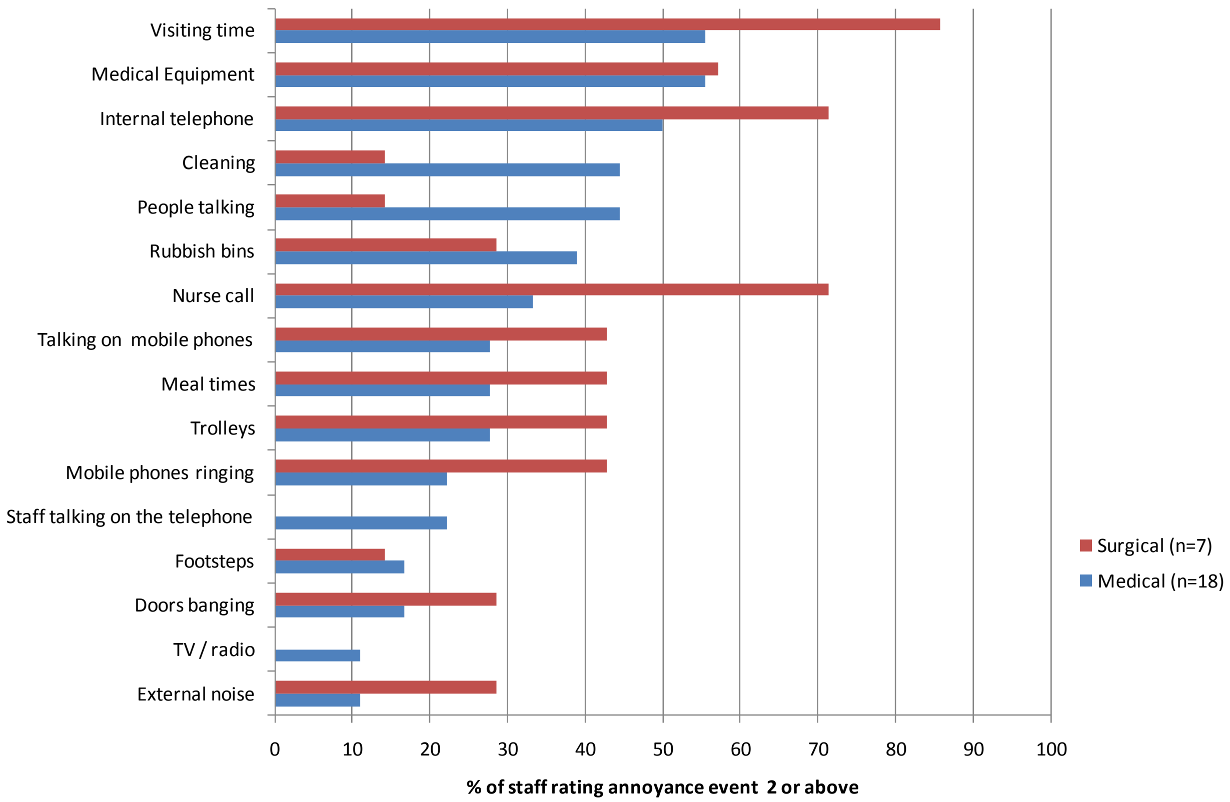


**Figure 2:** Percentages of staff annoyed by specific noise events

For 10 out of 16 noise sources, the percentage of those annoyed on the surgical ward is higher than on the medical ward. This could of course be simply down to the smaller sample size, and the possibility that only those staff who felt strongly about noise felt inclined to complete the questionnaire. However, other factors could also account for this difference. Medical and surgical wards are different, and as such may attract staff with different types of personality. Surgical wards are very busy with constant admissions for day or even half day procedures. Operations are booked in advance and efficiency and timing are key. Medical wards are slower paced and it is possible that staff annoyance of particular events could be less extreme.

## Noise interference

Respondents were asked to what extent noise interfered with their ability to work effectively. As can be seen in Figure 3, opinion of the respondents in the surgical ward was very split, whereas the majority of medical ward staff chose ‘slightly’ or ‘not at all’. This could again be due to the smaller sample size and differences suggested in the above section.

Staff were also asked to rate how much each noise event interfered with their ability to carry out their job effectively (again the rating scale of 0 ’not at all’ to 4 ’very much’ was used). Figure 4 shows the percentage of staff who rated a noise event with a 2, 3 or 4, indicating that the event interfered to some extent with their ability to carry out their job effectively.

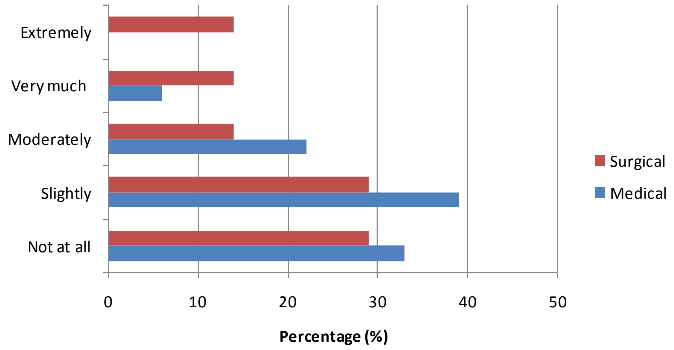


**Figure 3:** Staff perceptions of the extent to which noise interferes with work

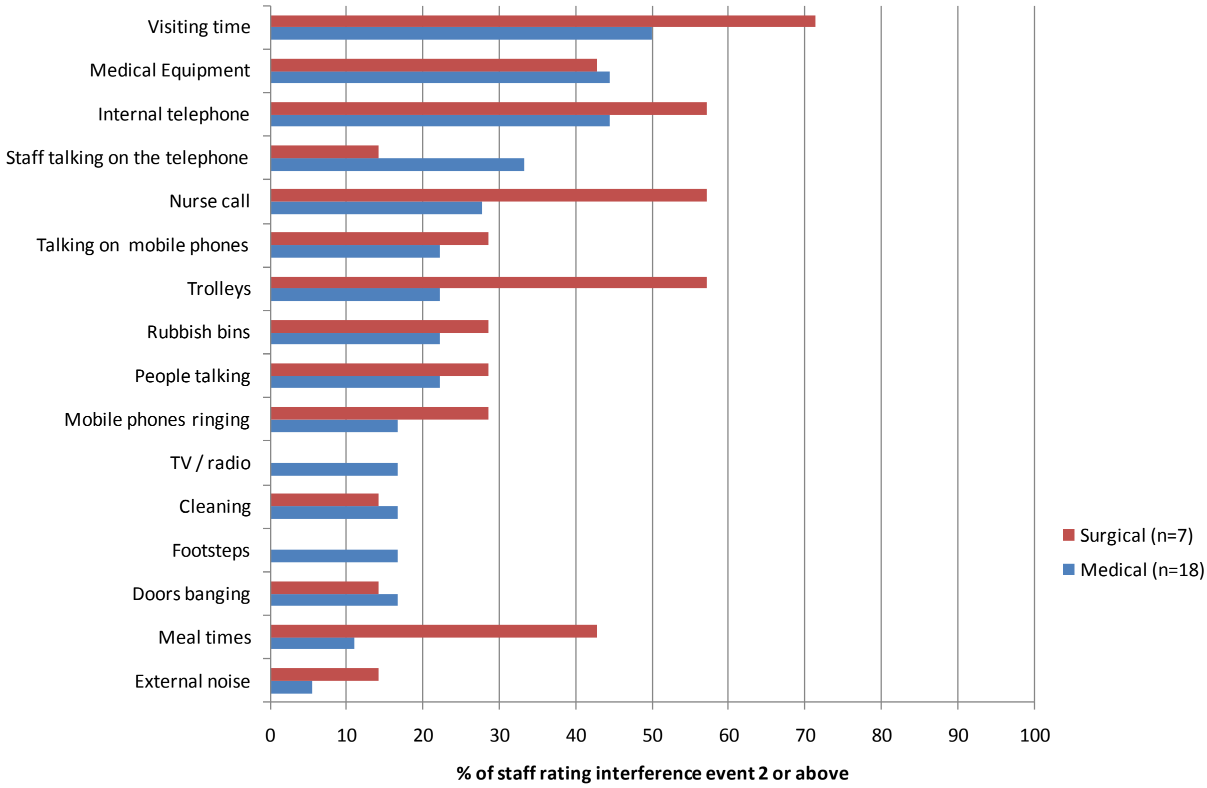


**Figure 4:** Percentages of staff experiencing interference with work by noise events

As with the noise annoyance ratings, visiting time, medical equipment alarms and the internal telephone were all rated as interfering with work by over 40 % of respondents in each ward.

There are several anomalies worth noting. The nurse call is once again rated by a high percentage of surgical staff as well as the trolleys and meal times; however, none of these are rated by a high percentage of medical staff. Trolleys are used in both wards a great deal, but in the surgical ward patients are often being wheeled through the ward to and from surgery and X-ray. It is unclear why meal times would be more disruptive to staff in the surgical ward.

## PATIENT PERCEPTIONS

A patient questionnaire was designed to investigate patient perceptions of day time noise annoyance and night time noise disturbance. The questionnaire sought to identify the particular sources of noise that may annoy or disturb patients. Patients were additionally asked about sounds they might find comforting, and their views on privacy.

## Day time noise annoyance

Patients were asked how they perceived the day time noise environment on the ward. Figure 5 details the responses, which are almost evenly distributed between 'quiet' and 'a little noisy'. Interestingly, when asked whether they were actually annoyed by noise, only 13 % of patients in the medical ward felt annoyed, and 29 % of patients on the surgical ward.

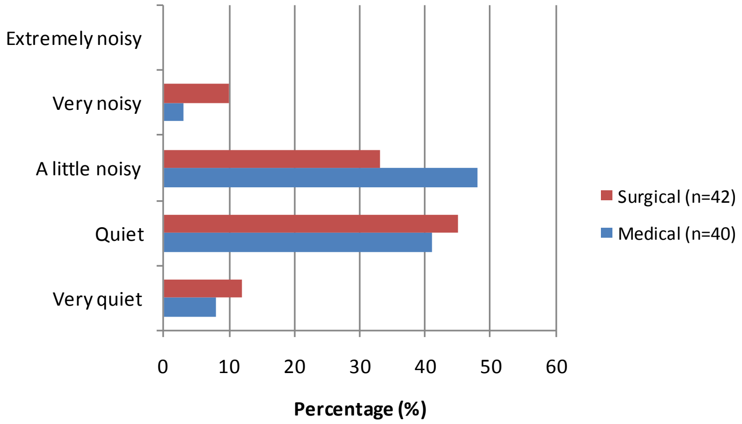


**Figure 5:** Patient perceptions of the day time ward noise environment

The patients who had indicated that they were annoyed by noise during the day, were then asked to rate the annoyance of various noise sources on a scale of 0 to 4, with 0 indicating 'not at all annoying' and 4 indicating 'a great deal'. With a relatively small number of people annoyed by day time noise the sample size was low (n=5 for the medical ward and n=11 for the surgical ward). Figure 6 shows the percentage of patients within this sample who rated a noise event with a 2, 3 or 4, and hence are more than a little annoyed by the event.

It can be seen that patients crying out, trolleys, internal telephones and rubbish bins (to a lesser extent in the medical ward) appear to be sources of annoyance in both wards. One particular difference is that doors banging is rated by nearly 60 % of patients on the surgical ward, but by no one on the medical ward. As discussed in the staff questionnaire section, there is one particularly heavy fire door at the end of the ward corridor which was mentioned as a problem in initial discussions with staff.

Other noticeable differences are the annoyance caused by visiting time, footsteps, nurse call and external noise. All these events are only cited by patients in the surgical ward. As discussed previously, external noise may be more of a problem during the study period in the surgical ward as the weather was warmer and more windows would have been open. Talking on mobile phones and tv/radio are the only events that are cited by medical patients only. This could be due to a lack of enforcement of mobile phone policy, and the non-compulsory use of headphones.

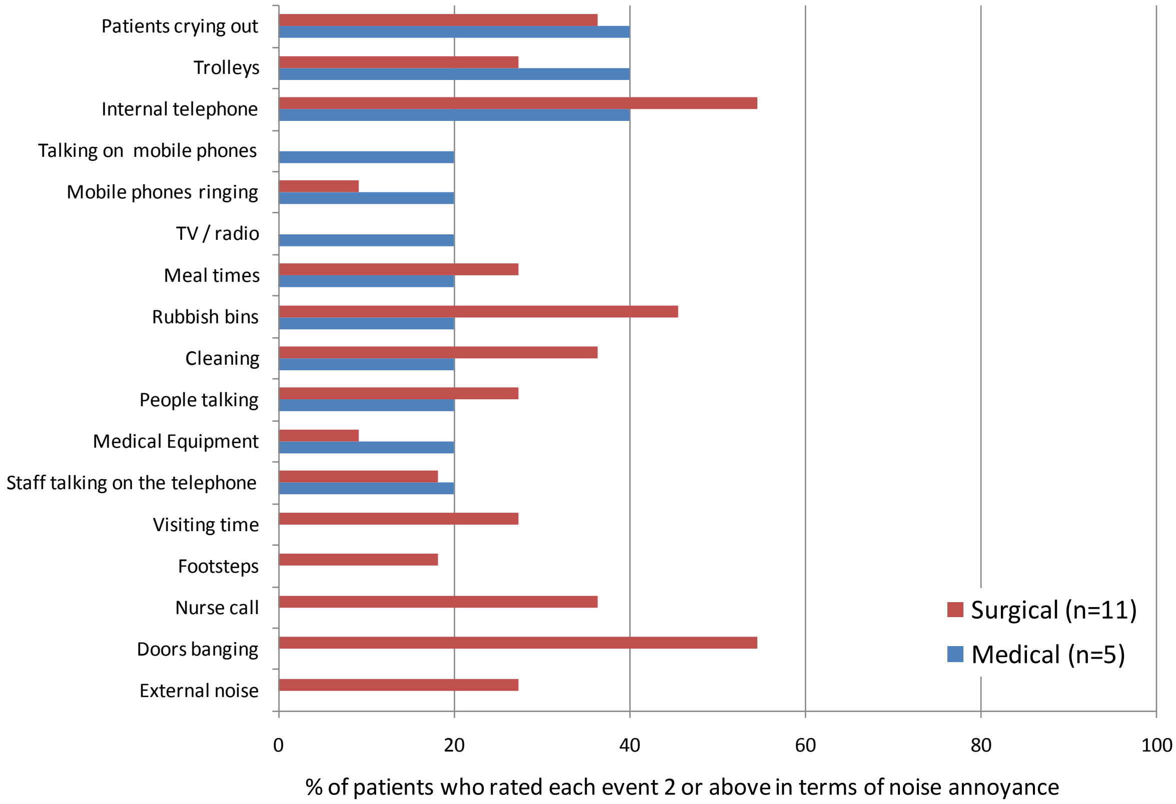


**Figure 6:** Percentages of patients annoyed by specific noise events

## Night time noise disturbance

Patients were also asked how they perceived the night time noise environment on the ward. Figure 7 details the responses, where again the majority of the responses were split between 'quiet' and 'a little noisy', but with a noticeably higher percentage (18 %) in the medical ward choosing the 'very noisy' category than during the day.

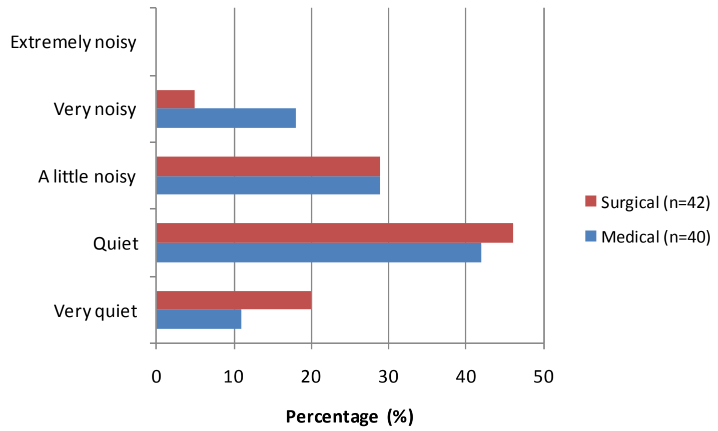


**Figure 7:** Patient perceptions of the night time ward noise environment

When asked whether they were disturbed by noise at night, 58 % of patients in the medical ward felt they were, compared with 51 % of patients on the surgical ward.

Patients who had indicated that they were disturbed by noise during the night were asked to rate the annoyance of various noise sources on the same scale of 0 to 4.

Sample sets were higher than for the day time annoyance (n=23 for the medical ward and n=19 for the surgical ward). Figure 8 shows the percentages of patients within this sample who rated a noise event with a 2, 3 or 4, and thus were more than a little disturbed by the event.

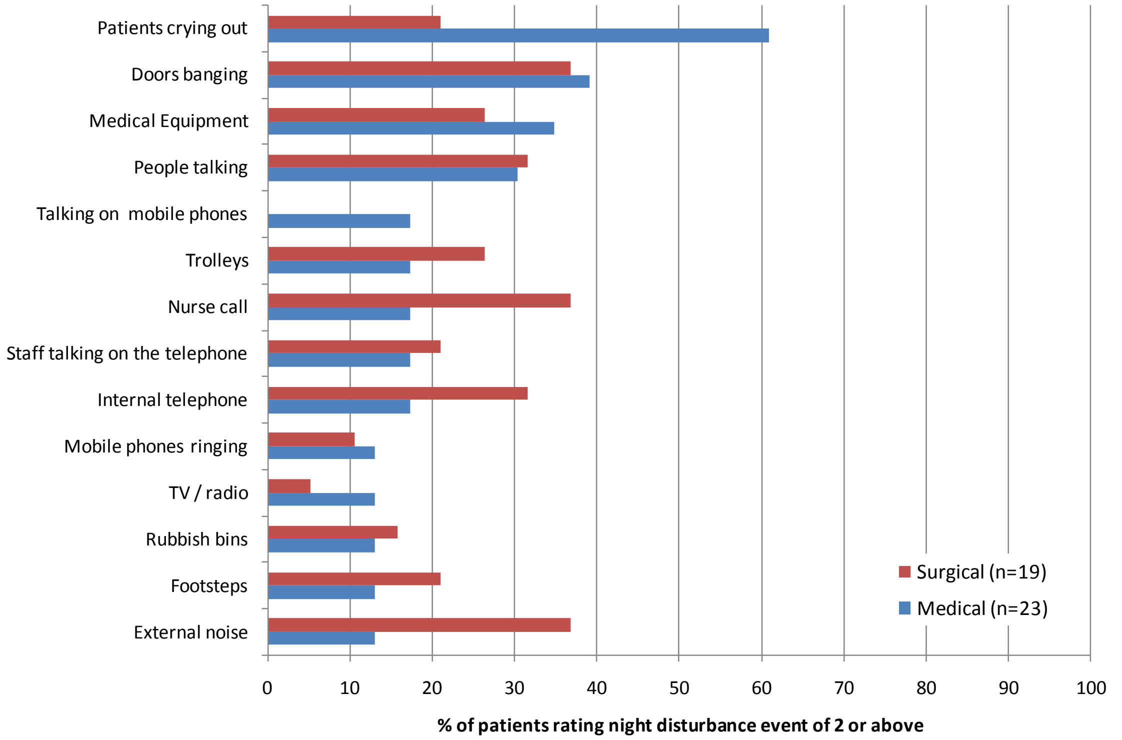


**Figure 8:** Percentages of patients disturbed by specific noise events

It can be seen that certain events which were rated as annoying by surgical patients only during the day, cause a level of night time disturbance in both wards. Doors banging, the nurse call, footsteps and external noise, are all rated as disturbing (although slightly less so on the medical ward).

One noticeable difference is that 'patients crying out' seems to be much more of a problem on the medical ward during the night. This is possibly related to the number of elderly patients suffering from confusion and dementia on this ward, who tend to cry out more often.

'Talking on mobile phones' is still cited as a disturbance only on the medical ward. Again this may indicate a lack of policy enforcement by the staff on this ward.

## Positive sounds

Looking at sound in a positive rather than in a negative light, patients were asked if there were any sounds that they actually found comforting. Over 70 % of patients in both wards left the answer blank, but there were thirteen completed responses. Several respondents cited external noise such as birds or traffic as it made them feel as though they were not completely cut off from life outside the ward. Music on the radio was felt to be comforting, as was the sound of the approaching tea trolley. Knowing that staff were close at hand for care and support was also cited by a number of respondents.

**Privacy**

Conversation privacy was investigated by asking whether the patient felt that they could have a private conversation at their bedside. 75 % of patients in single rooms said that they felt they could speak privately, with lower percentages in the multi bed bays of 67 % and 64 % in the medical and surgical wards respectively. Out of those who felt they could speak privately, around 40 % said they felt they could talk in their normal voice, with 60 % needing to lower their voice or taking some other precautionary measure – similar percentages were found in both wards.

## CONCLUSIONS

Results from the questionnaires confirm that noise is a problem for both staff and patients. Over half the patients questioned felt that they were disturbed by noise during the night, a time when they should be able to rest and recuperate. Staff responses indicate that they are not only annoyed by noise, but that it impacts on their ability to carry out their job effectively.

Some noise sources cited by patients and staff alike could be improved with simple changes to behavior and enforcement of hospital policies, for example being aware of the impact of cleaning; of loud conversations; and ensuring that calls are not made on mobile phones and that phones are set to silent mode on the ward. Other sources of disturbance, for example banging doors, are the result of poor maintenance. Equipment noise and design is a major issue. Nurse call systems, internal telephones and medical equipment are continually cited by staff and patients as sources of annoyance and disturbance. It should be possible, through collaboration between manufacturers and system users, to design and locate equipment so that noise problems are minimized.

In this hospital the ward construction and layout also appear to have a negative impact regarding patient disturbance. The kitchen, ward clerk's desk and nurse station, which generate noise annoying or disturbing to patients, are all situated very close to patients' beds. External noise could be attenuated through the use of double glazing with mechanical ventilation; however, with some patients expressing positive views on being able to hear the world outside, this solution might not be ideal.

Further work involves relating the questionnaire responses to objective acoustic data in order to identify those aspects of noise which affect perceptions and suggest ways of mitigating adverse effects on staff and patients.

## ACKNOWLEDGEMENTS

The authors wish to thank the UK Engineering and Physical Sciences Research Council and Arup for funding this study, and the staff and patients in the hospitals.

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# A pilot study of noise level in a pharmacy department in a teaching hospital

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## INTRODUCTION

Noise can be defined as an unwanted, intense, annoying or unexpected sound. Sound that interferes with the perception of a desired signal can also be defined as noise (enHealth Council 2004). Besides hearing loss, workplace noise exposure is related to many other adverse effects (Berglund et al. 1999). Noise interferes with speech perception and alters sustained attention both of which can cause workflow interruptions (Sbihi et al. 2010). Noise in the workplace also induces annoyance; increases fatigue and stress (Jansen & Schwarze 1988; Topf & Dillon 1988; Lazarus 1998; Berglund et al. 1999). Noise is associated with an increase in the number of errors in work for complex cognitive tasks (Mosskov & Ettema 1977a, b; Smith 1990; enHealth Council 2004) whereas for repetitive manual tasks, noise can enhance vigilance (Ising et al. 1980; Auburn et al. 1987). In hospital settings, the World Health Organization (WHO) recommends to limit the noise to an equivalent continuous noise level ($L_{Aeq}$) lower than 30 dBA inside the room not to disturb patient's sleep and rest (Berglund et al. 1999). However, the quality of the acoustic environment in hospitals is often very noisy (Busch-Vishniac et al. 2005). Studies have showed that noise levels varies in "quiet" hospitals between 40 to 50 dBA, from 50 to 60 dBA in "moderately noisy" ones and between 60 to 70 dBA in "very noisy" hospitals (Mazer 2002; Pereira et al. 2003; Busch-Vishniac et al. 2005).

In hospital pharmacy, workflow interruptions have been associated with dispensing errors (Flynn et al. 1999). Since noise has been associated to workflow interruptions, one could predict that dispensing errors would also be related to noise levels and signal-to-noise ratio (Flynn et al. 1996; Lambert et al. 2010). Only a few studies have been conducted about noise in hospital pharmacies. Reported noise levels vary from 55 to 68 dBA (Pai 2007; Otenio 2007). Given the paucity of data on ambient noise levels in hospital pharmacies and the recent introduction of robotic technology to prepare and track medications, this study measured the noise levels in different working areas of the central pharmacy of Centre hospitalier universitaire (CHU) Sainte-Justine in Montreal Quebec, Canada.

## METHODS

Measurements were carried out in nine working areas of the central pharmacy. Figures 1 to 4 show the floor plans of the nine different zones (1-9) and indicate the sampling sites (A-X) used for noise level measurements. Two technicians work in zone 1 (Figure 1) picking unidose medications and loading ward carts for the dispensing to the inpatients. One technician works in zone 2 (Figure 1) preparing the narcotics. Five to seven employees work in zone 3 (Figure 2) that is devoted to the compounding of non-sterile preparations. One technician works in zone 4 (Figure 3) and prepares prescriptions for outpatients. One employee is assigned to zone 5 (Figure 3) which is used for storing medications. Zone 6 (Figure 2) is the anteroom to the sterile compounding room (zone 7 – Figure 2) where positive air pressure is maintained. Up to six employees work within this room processing sterile pharmaceutical preparations. There are seven laminar airflow hoods in this room and two of these are equipped with a sterile pressure pump. Zone 8 is a working space shared by students and clerical support staff. Zone 9 (Figure 1) is devoted to packaging; an automated packaging machine regularly runs in this space. With the exception of zones 6 and 7, the central pharmacy is laid out as an open-space. A large number of noise sources were identified in this environment: ventilation system, computers (constant operation), radios, refrigerators, printers, pneumatic delivery system, packing machines, ventilation hoods, pumps, phone ringing and employees' conversations.

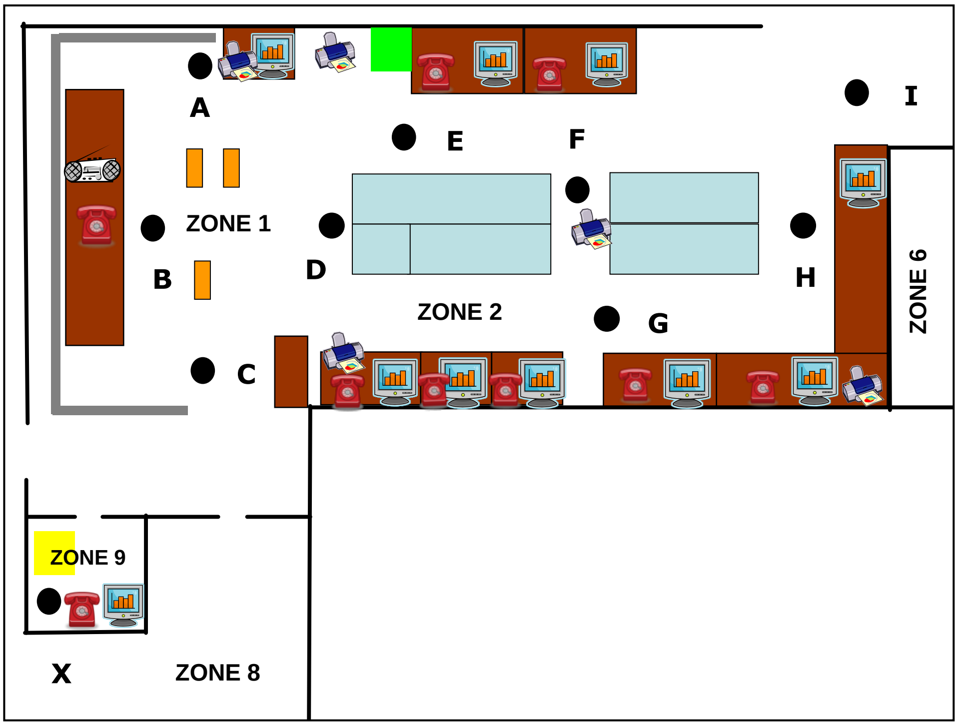


**Figure 1**: Floor plan zones 1, 2 and 9. Sampling sites (●).

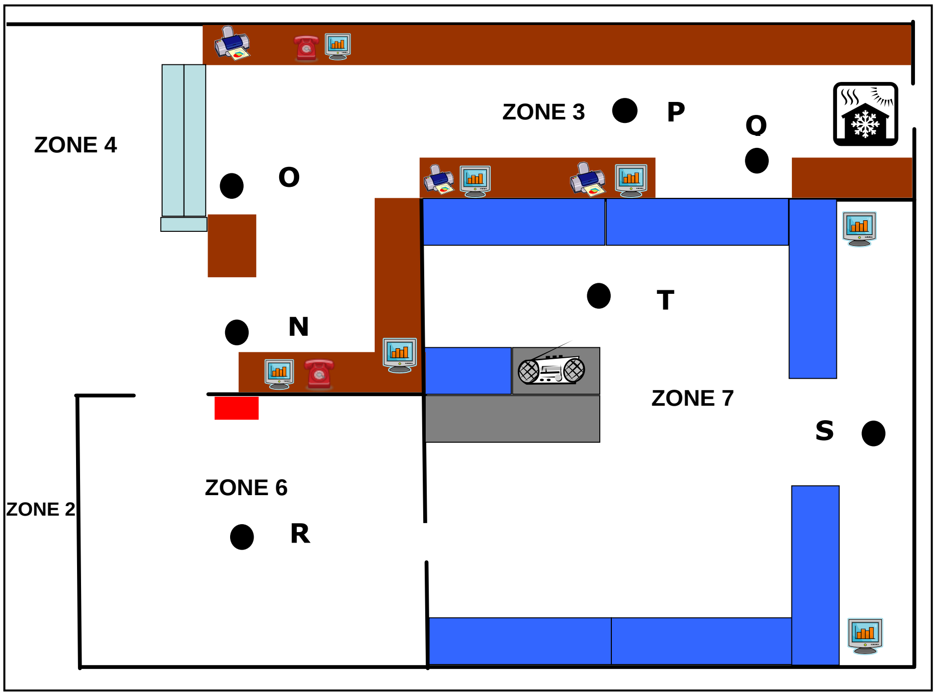


**Figure 2**: Floor plan zones 3, 6 and 7. Sampling sites (●).

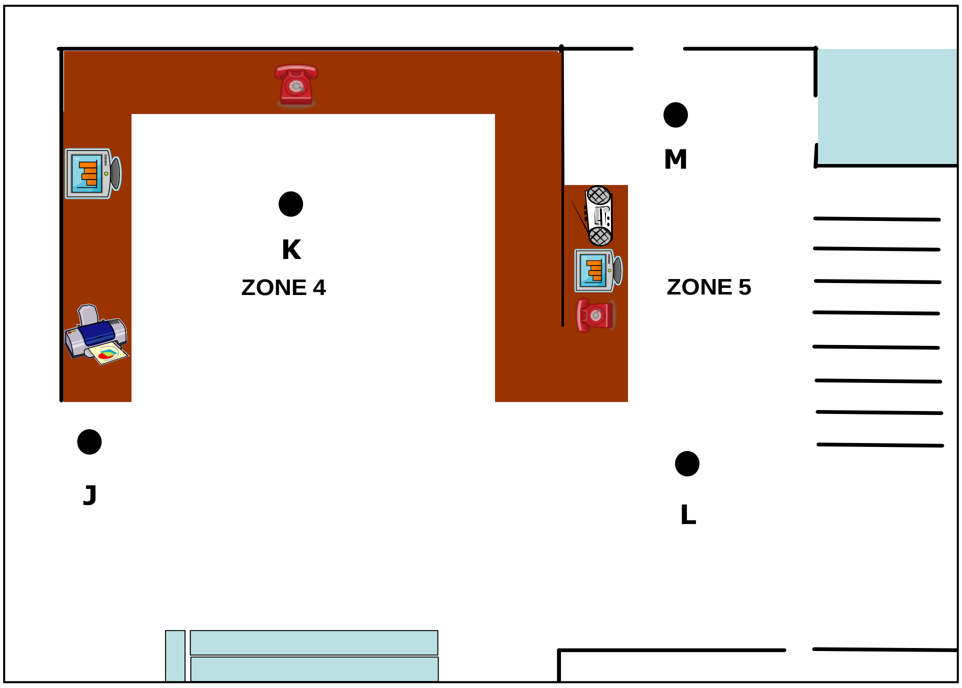


**Figure 3**: Floor plan zones 4 and 5. Sampling sites (●).

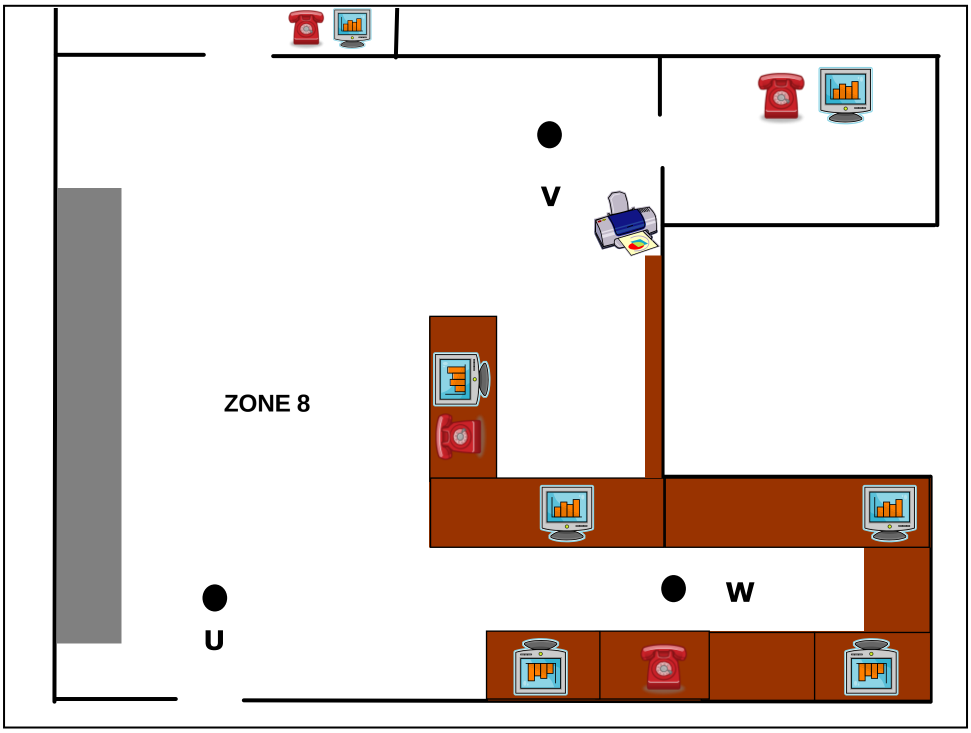


**Figure 4:** Floor plan zone 8. Sampling sites (●).

Noise levels were measured during three measurement periods, Day 1 and Day 2 from 9 am to 4 pm and Day 3 from 6 pm to 8:30 pm. An integrating sound level meter (TES-1353, type II) was set on slow response and installed on a 1.45 m tripod with the microphone oriented upward. The sound level meter was calibrated *in situ* by the use of an acoustic calibrator (94 dB SPL, 1 kHz) prior to and following each measurement session. $L_{Aeq\text{-}5min}$ were obtained twice for each sampling site. This sampling duration was considered long enough to include fluctuations usually found in this environment. Equivalent noise levels were averaged over measurement periods [day (Ld), evening (Le)]. In each zone, day and evening levels were compared with Student t-tests using p<0.05 for level of significance.

## RESULTS

Data from different sampling sites were pooled across working zones and daytime period of measure. Repeated daytime measurement led to fairly similar levels with a few exceptions. Average noise level (in dBA) was higher during the day (Ld = 59.4 ± 5.3) than the evening (Le = 52.8 ± 8.2) [p<0.001]. The zones, in increasing order of maximum average noise level in dBA observed during the day (Ld) or the evening (Le), were the shared office area [Le:43.0; Ld:50.5], storage area [Le:53.8; Ld:57.8], dispensing/narcotics area [Le:51.4; Ld:58.5], dispensing/unidose manual picking area [Le:47.2; Ld:58.7], packaging [Ld:60.5], dispensing/outpatient area [Le:57.0; Ld:60.6], non sterile compounding area [Le:50.3; Ld:62.0], sterile anteroom [Ld:62.1; Le:63.4] and the sterile compounding area [Le:69.9; Ld:70.4]. Noise levels were found higher in areas with controlled positive ventilation, automation and higher number of workers. Table 1 provides detailed results.

**Table 1:** $L_{Aeq-5min}$ measured in nine working zones of the central pharmacy

| Sampling sites | Day (Day 1) | Day (Day 2) | Evening (Day 3) | p value |
|---|---|---|---|---|
| Zone 1 - Dispensing/unidose manual picking area | | | | |
| A | 60.5 | 60.2 | 45.6 | NA |
| B | 54.3 | 57.0 | 47.0 | NA |
| C | 58.6 | 59.1 | 48.2 | NA |
| D | 59.6 | 60.1 | 48.1 | NA |
| Mean | 58.7 | | 47.2 | <0.0001 |
| Zone 2 - Dispensing/narcotics area | | | | |
| E | 59.7 | 62.6 | 47.8 | NA |
| F | 59.0 | 56.2 | 53.2 | NA |
| G | 57.5 | 59.0 | 46.9 | NA |
| H | 57.4 | 57.0 | 57.0 | NA |
| I | 58.6 | 57.8 | 51.9 | NA |
| Mean | 58.5 | | 51.4 | 0.0004 |
| Zone 3 - Non sterile compounding area | | | | |
| N | 59.4 | 58.8 | 53.5 | NA |
| O | 61.2 | 60.9 | 54.6 | NA |
| P | 63.5 | 68.0 | 50.3 | NA |
| Q | 62.4 | 61.9 | 42.8 | NA |
| Mean | 62.0 | | 50.3 | 0.0005 |
| Zone 4 - Dispensing/outpatient area | | | | |
| J | 61.3 | 60.6 | 60.0 | NA |
| K | 59.8 | 60.8 | 54.1 | NA |
| Mean | 60.6 | | 57.0 | >0,05 |
| Zone 5 - Storage area | | | | |
| L | 59.0 | 59.0 | 53.1 | NA |
| M | 53.2 | 59.8 | 54.4 | NA |
| Mean | 57.8 | | 53.8 | >0,05 |
| Zone 6 - Sterile anteroom | | | | |
| R | 62.3 | 61.9 | 63.4 | NA |
| Mean | 62.1 | | 63.4 | >0,05 |
| Zone 7 - Sterile compounding area | | | | |
| S | 68.9 | 69.3 | 69.7 | NA |
| T | 71.5 | 71.8 | 70.1 | NA |
| Mean | 70.4 | | 69.9 | >0,05 |
| Zone 8 –Shared office area | | | | |
| U | 51.3 | 51.8 | 43.1 | NA |
| V | 44.8 | 49.8 | 38.6 | NA |
| w | 55.2 | 49.9 | 47.4 | NA |
| Mean | 50.5 | | 43.0 | 0.02 |
| Zone 9 – Medication packaging | | | | |
| X | 60.5 | ND | ND | NA |
| Mean | 60.5 | | ND | NA |
| Overall mean | 59.4 | | 52.8 | <0.0001 |

NA: not applicable; ND: not done

## CONCLUSIONS

Overall mean noise levels were significantly higher during the day (59.4 dBA) compared to the evening (52.8 dBA) a finding similar to available data collected by others researchers. Pai (2007) conducted a study in Taiwan in a large hospital (1,650 beds) and reported average noise levels for the pharmacy at 62.5 dBA in the morning, 63.9 dBA in the afternoon and 55.8 dBA at night. Otenio et al. (2007) sampled noise levels in a smaller hospital in Paraná, Brasil (222 beds). The noise levels measured between 7 am and 7 pm, varied from 58 to 66 dBA, with a mean value of 63.3 dBA. Night noise levels were lower, between 58 to 60 dBA most of the time. However, it is difficult to compare the absolute noise levels across studies because of methodological differences in the noise measurement methods (duration of integration time and exchange rate to cite a few), architectural and equipment differences in pharmacy's settings.

In our study, some working zones were markedly noisier than others (sterile compounding area > medication packaging > shared office zone). Higher noise levels can be explained by the presence of mechanical equipment (ventilation hoods, automated packing machine) and the number of employees simultaneously present in the open-space. Similar observations were made by Mendoza-Sánchez et al. (1996) who measured noise levels in various zones of a hospital. These authors found that high noise levels in the intensive care unit (ICU), above 59 dBA, were caused by the presence of numerous devices such as monitors, continuous infusion pumps, mechanical ventilation devices and alarms. Similar results, noise levels around 61 dBA, were reported for a neonatal ICU by Laroche & Fournier (1999). For hospital pharmacy, the introduction of robotics and automated machines could have the same cumulative effect and progressively increase the noise levels in this working environment.

Our results show preoccupying noise levels for hospital pharmacy given the demands imposed by the nature of the work: sustained attention required to complete complex processes, interference-free communication and frequent interruptions (Flynn et al. 1999). In open-space office, insuring interference-free speech communication imposes a limit for the level of noise of 48 dBA (Bradley 1985). The average daytime noise level obtained in this study exceeded this criterion by more than 10 dB (a ten-fold difference). Using this sole criterion, leaving aside other important aspects of the problem such as the adverse effect of noise on sustained attention and number of errors during complex cognitive tasks, one would predict that such noise levels could be associated to dispensing errors in hospital pharmacy practice. Flynn et al. (1996) reported that the dispensing error rate increased with sound pressure levels up to 74 dBA ($L_{Aeq\text{-}30m}$) and decreased for higher levels. In a study, conducted mainly in community pharmacies, Flynn et al. (2002) found a significant association between dispensing errors and ambient noise made from radio or television for sound pressure levels lower than 75 dBA. In a laboratory controlled study conducted with pharmacists, Lambert et al. (2010) showed that the verbal recognition of drug names was significantly influenced by the signal-to-noise ratio. Signal-to-noise ratios of 8, 5 and -2 dB were roughly associated with error rates of 25, 50 and 75 % respectively. Our results suggest that the noise levels within the hospital pharmacy might create challenging communication situations in terms of low signal-to-noise ratio which may interfere on different demanding tasks.

While this study has a number of limits (restricted number of sampling days, short duration of the integration time, possible influence of level of activity within the pharmacy, noise levels not taken at ear level for the workers), the results are solid enough to justify a more detailed study. Such a study would have to include a more thorough assessment of the acoustic environment (assessment of signal-to-noise ratio) and specific outcomes measures about work-related and noise-related stress, fatigue and systematic observation of dispensation errors. However, pharmacists and management teams should not wait to integrate the “noise aspect” in their plans before buying or installing robotic and automated equipments in order to maintain or create a better auditory environment for pharmacy practice in hospitals.

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# Getting it together - Interdisciplinary Sound Environment Research

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*The recently published report "Burden of disease" from The World Health Organization (WHO) states that health impact of environmental noise is a growing concern both for the general public and politicians and policymakers of Europe.*

*The so called Environmental Burden of Disease (EBD) are measured in DALY´s - Disability Adjusted Life Years (the sum of potential years of life lost due to premature death and the equivalent years of healthy life lost by virtue of being in states of poor health or disability). The report estimates that 61,000 years are lost in ischaemic heart disease, 45,000 years for cognitive impairment of children, 903,000 years for sleep disturbance, 22,000 years for tinnitus and 587,000 years for annoyance. In other word more than one million life years are lost every year in Europe (WHO 2011).*

*The novel, if somewhat adventurous, way of measuring the effects of noise on society clearly shows that noise as a public health problem is a growing topic today on the agenda of taking control of environmental threats of modern society. Persistent research from acoustics, environmental medicine and other academic disciplines is now showing results, as this conference shows. Noise awareness can be added to other environmental issues in public consciousness such as climate change, water, air and food pollution and similar threats.*

*Researchers and laymen involved in the struggle for better sound environments and sound awareness however know that sound environments and disturbance often turns out to be complicated things to handle for many reasons.*

## INTRODUCTION

The Sound Environment Center at Lund university in Sweden has been the first interdisciplinary research Center created with an aim to especially coordinate research on sound and soundscape issues. The center connects areas of the academic field that often exists in separate worlds and seldom has possibilities to meet or conduct research together.

Ranging from acoustics to medicine and psychology as well as musicology and cognitive studies, soundscape research addresses many interdependent areas and topics. To be able to get a more complete comprehension on soundscape and sound environments, the need for this multitude to be synchronized and be put in relation to each other is put in focus in this center.

Human perception of sound environments and how sound is interpreted by human mind and body is a complex one in itself. As sound is always perceived in combination with other sensory sensations and inputs, studying the reactions to sound in man involves measurements and description of a multitude of qualities, raising a need of quantification of many parameters, including some that have yet to be defined. This goes for the complex perception of quality and character of sounds. The characteristic of the sound environment experience is that it almost never stops at sound alone, but involves multisensory perception as well makes it all the more difficult to handle scientifically.

The sound environment experience includes the perception of auditive space and perspective to be taken into account, the sonic space in which a certain degree of auditive transparency allows you to hear distant or weak sounds. This can largely affect our sense of orientation and security. One could almost say that sound environments can be a question of democracy in the sense that small sounds must be able to also be heard!

Sound environment studies involves cognitive and emotional aspects and also ethics in our ways of dealing with, and generating sound, reflecting individual and social behaviors. Heavy parts are however about data interpretation and analysis. Especially disciplines like acoustics and audiology are largely dependent on instrumentation, measurement techniques and protocols, raising questions of uncertainties and theory, and standardizations.

Another one of the characteristic issues of sound is the intangibility: when its there, its there and when its gone, it´s gone as if it´s never been there, leaving no scars (if your hearing hasn't got seriously damaged of an extreme exposure, or your blood pressure or stress hormones hasn´t risen as an effect of the traffic outside your bedroom window. The intangibility aside, the costs of noise doesn´t disappear. The more we take into account of prevention and health care that can be related to noise, the costs rises momentarily.

## SOUND ENVIRONMENT RESEARCH

A rough list of topics reported on in this conference gives quite a good picture of where sound environment research stands today and the scope of the whole field. This ICBEN conference encompasses some 190 presentations (including poster ones) and a preliminary list of themes includes the following: hearing, health, sleep disturbance, noise dosimeters, hearing in high noise, mp3 listening, transport noise, wind turbine noise, cardiovascular effects of noise, blood pressure, cognitive impairment, room acoustics and work performance, intensive care unit noise, multisensory experience in historical places, health costs, noise policies, noise sensitivity, noise during pregnancy, children health and noise, noise as social determinant, urban soundscapes, hearing loss among classical musicians, hearing and age, vuvuzelas and health risks, acoustics and noise exposure among musicians, hyperacusis, classroom acoustics and fatigue, quiet areas, cardiovascular noise tests on rats, memory and noise, metrology and noise, masking noise, shooting noise, pesticides, noise and farm workers etc. etc.

Each one of these makes perfect sense, we understand easily what is meant, our common everyday experiences clicks in at once. We experience all the topics as relevant, and the list makes the vastness and the scope of this field clear. Back home in our everyday life and in research institutions, however, we are often stuck within our different disciplines.

## AN INTERDISCIPLINARY ACADEMIC RESEARCH CENTER

At Lund University in the south of Sweden, a few years ago the thought was born to constitute an interdisciplinary Center for research and information on our sound environment. The Center was designed after a preliminary study made by prof. Henrik

Karlsson (Karlsson 2006). This was a study relying on a lifetime work and engagement in soundscape issues and together with some diplomacy and energy the study managed to convince the vice chancellor to provide funding for *The Sound Environment Center* at Lund University.

The main thought behind this was as mentioned that the complexity of sound environmental research must involve many different perspectives in a wide array of academic traditions and faculties. This goes for both the defining of the problems as well as searching for solutions and answers.

To illustrate the situation with a simple picture: The general situation of how sound environment issues are dealt with by society could be described as large commode with many different drawers (Karlsson 2005). Each one in it´s own way dealing with sound and sound environments. One drawer for traffic noise, one for railway transports, one for toys, one for music and entertainment, one for research, one for architecture etc. etc. The same fragmentation happens in the academic world: one drawer for ethics, one for acoustics, one for health medicine, one for sound design and so on. One for road traffic… and never shall they meet!

Questions of soundscapes, health and noise problems are slowly emerging to a common awareness today. Research and invention are being done on fine detailed levels and must avoid the risk of this fragmentation, and the Sound Environment Center at Lund University in Sweden believes that it is important to do what we can to create and stimulate networks for interdisciplinary research.

## ORGANIZATION

The Center has a board of representatives of academic subjects as acoustics, ergonomics, psychology, musicology, audiology, environmental medicine, health economics etc. and has been provided with a three year period of funding at a time for basic functions, such as keeping a coordinator, daily costs of office tasks, printing costs etc. In addition to this, the Center applies separately for funds for the specific research projects to external sources. Administratively the Center belongs to the faculty of humanities and the department of cultural studies, but is independently run.

In addition to the board of the Center, a research reference group has been put together as well as an international group of mentors connected. The Center has also initiated an informal meeting with other interdisciplinary resources at the university and representatives of the industry working with sound environmental problems such as Volvo, Sony Ericsson, Trelleborg and others. It keeps its own website (www.ljudcentrum.lu.se) on the Lund university server and promotes networking in general when and wherever possible. Plans are being made for a local *Sound Environmental Advisory Board* and a *Friends Of The Sound Environment* network open to funding by private persons as well as co-operations. In short the center tries to stimulate collaborations among soundscape researchers, practitioners, and designer/composers to establish knowledge in this emerging area.

The Center has established cooperation with the Swedish counterpart to the International League for the Hard of Hearing, *Hörselfrämjandet,* in promoting the annual *International Noise Awareness Day* in April. Other collaborators to be mentioned are Swedish Noise Network and The Swedish Acoustic Society. The Center was awarded The Swedish Acoustic Society´s Large Sound Prize 2008 for ”the innovative mobilization of power the center constitutes with an aim to coordinate and initiate interdisciplinary sound environmental projects with the human being in focus. Though interaction with society and contacts with industry and enterprise knowledge on sound is transmitted for the benefit of human health and well-being."

The Center was evaluated by the university after it´s first three year of activities and was there described as an activity (quote:) "bringing substantial added value to the university". It has recently also received a renewed three year funding for further development of interdisciplinary research that today provides seed money for a line of new projects.

SYMPOSIUMS AND PUBLICATIONS

The Sound Environment Center has since its start arranged a number of interdisciplinary symposiums on specific themes with relation to the study of sound environments. To each one a number of prestigious speakers and researchers has been invited. They have been able to present new research and discuss their findings with each other and a well filled auditorium crossing the borders of their individual disciplines. Recent themes have been: "Noise in the Wind" (Buller i Blåsväder) on wind turbine noise [2011], "Sound Environment Health and city planning" (Ljudmiljö, hälsa och stadsbyggnad) [2010]. Among earlier themes can be mentioned "Sound, mind and emotion", "Sounds in History", "Sound and health", "Sound Design" etc. Each symposium producing a collection of published papers. The Sound Environment Center has published a number of reports on various sound environment themes and topics (Mossberg 2006 - 2011). These can be ordered from center´s website, and are also available as full text pdf-files for download. So far most publications are in Swedish, but a growing number are published in English for international readers (Mossberg 2008; Mossberg 2009).

PROJECTS

The center is by now responsible for a number of ongoing research projects that has received funding from various external sources. Among ongoing and previous topics of study and projects within the framework of the center may be mentioned:

**Traffic noise, recreational values and health**

Investigating associations between residential exposure to traffic noise, positive recreational values of the natural surroundings, and health, using extensive longitudinal data from a baseline and a follow-up survey combined with Geographic Systems (GIS) data. Some of the major aims are: 1: Improved tools for modeling of exposure to traffic noise and access to positive recreational values, 2) To explore associations between these aspects of the residential environment and neighborhood comfort, physical activity, performance, recovery, overweight and hypertension.

**Health effects of simultaneous exposure of airborne particles and noise**

Another large project associated with the Center investigates simultaneous exposure of airborne particles and noise and if this can have noticeable combined health effects on humans. This project will involve cooperation of researchers from acoustics, cardiology, laboratory medicine and ergonomics.

As a follow-up to this project a further study in collaboration with researchers from Copenhagen and Gothenburg, will study how noise actually can affect the walls of individual cells on a micro/cellular level.

### Speakers comfort and voice disorders in classrooms (Brunskog et al. 2011)

Lead by ass. Prof. Jonas Brunskog of DTU in Denmark this project investigates the stress on voice production by different acoustic conditions with an aim to find guidelines for design of acoustic environments with focus on speakers as teachers and lecturers. The overall aim of the project has been to investigate the voice use of teachers in relation to the acoustic properties of the classroom, and to study whether speakers take into account auditory cues to regulate their voice levels, even in the absence of background noise (Brunskog et al. 2011) This project has received a four year funding from AFA – an insurance institute in Sweden and has as of today produced on dissertation (Lyberg Åhlander et al. 2011) and another one is on its way.

### Railway noise at different climatic conditions

A visualization of how noise of trains move through the landscape at different conditions of dampness and temperature – i.e. “atmospheric inversion”. This project has resulted in a film of the movement of the actual noise of trains affecting an exposed village close to Malmoe in an open landscape in southern Sweden. The film has been used in discussions with politicians on the planning of new railroad tracks through the area. This project was led by professor in landscape planning Erik Skärbäck at The Swedish University of Agricultural Studies SLU in Alnarp.

### Eye movement and cognitive disturbance vs. exposure to noise, sounds and music

Using advanced eye movement equipment at the laboratory of humanities in Lund the project will study how reading and understanding is affected by noise and music, wanted or unwanted (Johansson et.al 2011). This project wants to create a deeper understanding of the reading behavior to background sound. This is a joint interdisciplinary project between cognitive studies, psychology and musicology. The project uses measurements from eye-tracking and GSR - Skin Galvanic Response measures to gain knowledge of cognitive effects of sound exposure, be it noise, music or birdsong.

### Sound as sensory Impressions in virtual reality worlds - sound as determinant of orientation in virtual reality

At Ingvar Kamprad Design Center and the institute of ergonomics prof Gerd Johansson will look at how sound interact with the totality of sensory impression in virtual reality environments. This project will involve full scale virtual laboratory technologies in Lund.

### Sounds of nature as sounds of well being

Together with the SLU department of Landscape Planning at Swedish University of Agricultural Studies, a new study will look at what happens to sensory awareness when common rooms are fed with “natural” sounds as those of low amplitude bird song och sounds of woods and water. It is easy to treat noise problems as something that would exclusively be an urban phenomenon, but we feel that is equally important not to forget the sound environment in the countryside. Even there the picture might be complex and contradictory.

Sweden might seem like a quiet place in comparison with other parts of the world with lots of reasonably peaceful countryside and a moderately trafficked road system compared to many sound environments in central Europe and otherwhere.

Allowing oneself to generalize rather shamelessly, one could say the large areas of wilderness and rural areas have provided Swedes with solid references to fairly peaceful soundscapes that has made many people notice, hear and worry about the differences between noise and tranquility, and to appreciate natural environmental values enough to miss them when they are gone. “You sure do miss the silence when it´s gone”, Robbie Robertsson of the Band wrote in the song “Where do we go from here” in the late sixties and the words still rings true. The land reform in Sweden in the nineteenth century split up the villages in the countryside and resulted in farms and acres scattered all over the countryside. Something that today also have brought about that a lot of noise from the farming industry is scattered all over the land. This makes strong contrasts in sound environmental conditions apparent similarity at the same time, where you are very seldom allowed to forget about noise completely while enjoying tranquility.

## CONCLUSIONS

All in all the existence of an experiment like Listening Lund The Sound Environment Center at Lund university within the framework of a resourceful university like that of Lund shows that interdisciplinary collaboration opens up new possibilities and horizons. The university already possesses unique skills and credentials in fields relating to sound, such as acoustics, medicine, working environments, and architecture. Areas that are now brought together and strengthened in a number of research projects and other activities. The Center has been enhanced with closer contacts with related disciplines, potential financiers, and other partners. This work continues, deepens and expands as well as the series of symposiums.

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# Progress on noise policies: 2008 - 2011

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## EUROPEAN UNION

European Commission (EC) initiatives to improve noise policies across the European Union (EU) continue with considerable scientific and government support, with most of these efforts addressing issues related to the Environmental Noise Directive (European Commission 2002). The main EC policy website is: http://ec.europa.eu/environment/noise/home.htm, where the range of EC DG Environment activities related to noise policies may be viewed.

### Review of the implementation of the Environmental Noise Directive 2002/49/EC

The Dutch consultancies Milieu Ltd., Risk and Policy Analysis Ltd. (RPA) and TNO were contracted by the European Commission to conduct a project reviewing the implementation of the Environmental Noise Directive 2002/49/EC (END), as required by Article 11 of the END. The project ran from December 2008 until May 2010 and entailed three Tasks, summarized the project's objectives as follows:

- Task 1: To review the implementation of the key provisions of the Directive by the Member States (EU27) and to develop proposals for the amendment of the Directive, if considered appropriate;
- Task 2: To provide a comprehensive review of measures employed to manage environmental noise from key sources in the Member States; and
- Task 3: To develop an Action Plan outlining further implementation strategies and Community action on environmental noise, if considered appropriate.

Three separate reports have been produced on these tasks and can be made available upon request.

### ENNAH - the European Network on Noise and Health

As described on their web site (www.ennah.eu), "The ENNAH network is funded by the European Union to establish a research network of experts on noise and health in Europe. The network brings together 33 European research centers to establish future research directions and policy needs for noise and health in Europe. The Network will focus on the study of environmental noise sources, in particular transport noise, as well as emergent sources of noise such as noise from wind farms and low frequency noise. The network will facilitate high level science communication and encourage productive interdisciplinary discussion and exchange". ENNAH has the aim of influencing future EU policy by recommending research priorities on Noise and Health. The final ENNAH Conference is being held on 6 July 2011 in Brussels. The results of this important conference should be available afterwards.

## EUROPEAN ENVIRONMENT AGENCY (EEA)

### EEA Good practice guide on noise exposure and potential health effects

In November 2010 the European Environment Agency EEA published the outcome of work by its Expert Panel on Noise [Technical report 11/2010]. http://www.eea.europa.eu/publications/good-practice-guide-on-noise. The Expert Panel on Noise (EPoN) is a working group that supports the European Environment Agency and European Commission with the implementation and development of an effective noise policy for Europe.

The group aims to build upon tasks delivered by previous working groups, particularly regarding Directive 2002/49/EC relating to the assessment and management of environmental noise. The good practice guide is intended to assist policymakers, competent authorities and any other interested parties in understanding and fulfilling the requirements of the directive by making recommendations on linking action planning to recent evidence relating to the health impacts of environmental noise and, among others, the Night Noise Guidelines for Europe as recently presented by the World Health Organization. Specific Issues covered in this important document include Health endpoints, exposure-response relationships and thresholds for health endpoints, risk assessment and quality targets.

### EEA – Noise observation and Information Service

The EEA has updated and improved its Noise Observation and Information Service for Europe (NOISE) database. It now contains noise data for EEA member countries up to 30 June 2010. The data can be viewed in a user-friendly interactive map tool or can be downloaded in a variety of formats. For the first time, the map viewer also displays local noise contour maps for selected areas (see: http://noise.eionet.europa.eu/). NOISE provides, at the click of a mouse, a picture of the numbers of people exposed to noise generated by air, rail and road traffic across Europe and in 102 large urban agglomerations. Compiling information from 19 of the 32 EEA member countries, the NOISE database represents a major step towards a comprehensive pan-European service. Following the adoption of the Environmental Noise Directive (END), Member States were given until December 2007 to deliver relevant data. Users of the NOISE database can view the extent of data reported in accordance with the directive on a color-coded map.

## WORLD HEALTH ORGANIZATIN (WHO)

The World Health Organization (WHO) is not a policy-making organization. Instead, it provides scientific inputs to the noise policy making process. Thus, their reports need to be viewed as guidelines and recommendations, rather than regulations. In addition to other reports since 2008, WHO-Europe in 2009 published “Night Noise Guidelines for Europe” (WHO 2009), specifically examining the issue of sleep disturbance and other effects of nighttime aircraft overflights and providing noise guidelines for nighttime noise, including recommendations for noise metrics and noise exposure criteria.

This report is available for download from the WHO web site at (http://www.euro.who.int/__data/assets/pdf_file/0017/43316/E92845.pdf. As cited in this report, “Considering the scientific evidence on the thresholds of night noise exposure indicated by $L_{night,outside}$ as defined in the Environmental Noise Directive

(2002/49/EC), an $L_{night,outside}$ of 40 dB should be the target of the night noise guideline (NNG) to protect the public, including the most vulnerable groups such as children, the chronically ill and the elderly. $L_{night,outside}$ value of 55 dB is recommended as an interim target for the countries where the NNG cannot be achieved in the short term for various reasons, and where policy-makers choose to adopt a stepwise approach. These guidelines are applicable to the Member States of the European Region, and may be considered as an extension to, as well as an update of, the previous WHO *Guidelines for community noise* (WHO 2000).

The more recent WHO report, "Burden of disease from environmental noise - Quantification of healthy life years lost in Europe" (WHO 2011), was prepared by experts in working groups convened by the WHO Regional Office for Europe to provide technical support to policy-makers and their advisers in the quantitative risk assessment of environmental noise, using evidence and data available in Europe. The chapters contain the summary of synthesized reviews of evidence on the relationship between environmental noise and specific health effects, including cardiovascular disease, cognitive impairment, sleep disturbance and tinnitus. A chapter on annoyance is also included. For each outcome, the environmental burden of disease methodology, based on exposure–response relationship, exposure distribution, background prevalence of disease and disability weights of the outcome, is applied to calculate the burden of disease in terms of disability-adjusted life-years (DALYs).

The full WHO report may be downloaded from: http://www.euro.who.int/en/what-we-publish/abstracts/burden-of-disease-from-environmental-noise.-quantification-of-healthy-life-years-lost-in-europe.

COMMITTEE ON AVIATION AND ENVIRONMENTAL PROTECTION (CAEP)

In the fall of 2007, the International Civil Aviation Organization (ICAO) Committee on Aviation and Environmental Protection (CAEP) held a very important Workshop in Montreal, Canada entitled "Assessing Current Scientific Knowledge, Uncertainties and Gaps in Quantifying Climate Change, Noise and Air Quality Aviation Impacts". As described in the final report from the noise panel at this Workshop (Maurice & Lee 2009), "The CAEP process of assessing aircraft noise impacts is primarily based on the number of people exposed to significant noise as measured by day-night sound level, or DNL, which is not an assessment of impacts per se. This approach of quantifying people exposed should be modified to focus more specifically on the health effects or outcomes of aircraft noise exposure. For noise, the most appropriate definition of health is that of the World Health Organization (WHO), which indicates that health is 'a state of complete physical, mental, and social wellbeing and not merely the absence of disease, or infirmity.'

There are currently well documented exposure-response relationships for a number of health effects which can be applied presently by CAEP to the overall aircraft noise assessment process, except for sleep structure and coronary heart diseases (CHD). However, because air traffic has evolved from fewer operations with loud aircraft to more frequent operations with quieter aircraft, an update to exposure-response curves may be needed to better reflect current and projected air traffic operations. The workshop also noted that the applicability of and ability to generalize existing noise effects research data and related exposure-response relationships and thresholds to all countries is questionable and must be addressed.

As for air quality, CEA and CBA are potentially valuable tools for use in assessing the impacts of aircraft noise. However, the Noise Panel discussions noted that primary emphasis for aircraft noise impact assessment should focus on expanding exposure analyses. Noise panelists generally felt that economical assessment of noise impacts is challenging. Economists presented the state-of-the-practice in noise impact evaluation, based on housing value loss or contingent valuation surveys. But many among the Noise Panel expressed their concern that such economic impact models fail to capture the full extent of noise effects, such as the value of cardiovascular effects and the effects of sleep disturbance on worker productivity and worker accidents. Some panelists noted that DALY (disability-adjusted life years) and QALY (quality-adjusted life years) analyses, which are very well developed for air quality impacts, were also applicable to noise and had been used to compare noise and air quality impacts in airport analyses. However, other panelists felt that these methodologies were not yet widely agreed upon for noise impacts. Ultimately, panelists noted that most of them did not have economic expertise and that CAEP should seek further advice." Considerable additional information may be obtained on by downloading this important report from: http://www.icao.int/env/CaepImpactReport.pdf.

## INTERNATIONAL CONSORTIUM ON NOISE ISSUES IN DEVELOPING AND EMERGING COUNTRIES

Over the past decade or so, the European Commission (EC), the International Institute of Noise Control Engineering (I-INCE), the International Commission on Biological Effects of Noise (ICBEN), the World Health Organization and other Western governmental organizations and professional societies continue to address the negative effects of noise exposure and to make progress in developing effective and affordable approaches to improving ways to reduce these negative effects. Organizations such as the World Health Organization (WHO) and the International Commission on Biological Effects of Noise (ICBEN) are particularly influential because of their leadership of international efforts to improve the scientific foundation for noise policies and noise mitigation approaches for both community/environmental and occupational noise.

At the same time as significant improvements in predominantly Western noise policies have taken place, there is a concern about whether the approaches being taken by governments in developed, predominantly Western, countries are appropriate, affordable and technologically feasible for use implementation in developing and emerging countries, primarily in Asia, Africa and South America. This concern is largely based on the many differences between the "developed" and both "developing and emerging" countries concerning their available financial resources, differences in technological capabilities, differences in noise sources, differences in cultural expectations about the acceptability of various exposure sources, differences in climates, lifestyles, building construction techniques, etc. The attached diagram shows the variety of these influencing factors.

To address this serious concern, an international consortium of acoustics experts, academics, government representatives and relevant stakeholders has been developed to work together in a coordinated international effort to explore this issue and facilitate discussions necessary to coordinate noise research and noise policy efforts within developing and emerging countries. The goal is to gather and disseminate information needed for the implementation of modern noise mitigation techniques and noise control policies which match the circumstances of individual countries, not to impose predetermined solutions from Western experts. This project will involve holding a series of Workshops, Symposia and special technical sessions, especially at international acoustics conferences, to address this complex and difficult topic. These efforts are expected to lead to the publication of the results of the planned international discussions and, hopefully, future coordinated projects. We feel that a special effort is needed in order to better understand the differences between “developed” and “developing and emerging” countries, and the implications of these differences, for implementing adequate national and local community and occupational noise control approaches. The International Consortium will address this vitally important need, although additional membership and both organizational and financial support is sorely needed if it is going to be a success, especially support for the anticipated international Workshops at various acoustics conferences.

The International Consortium has been receiving steadily growing interest and a strong foundation for this effort is currently emerging. The International Commission on Biological Effects of Noise (ICBEN) is a major partner in the Consortium and the World Health Organization (WHO) has also expressed their encouragement for this effort. Additionally, support is also being received from the International Commission on Acoustics (ICA). Tsinghua University in Beijing, China has agreed to provide vital technical support to the International Consortium and other organizations are also involved.

## ACTIVITIES IN THE UNITED KINGDOM

### Department for Environment, Food and Rural Affairs (DEFRA)

The United Kingdom continues to make significant contributions to the noise effects research and noise policy-making activities. In July 2009 two key publications relating to Noise and Health, with implications for economic valuation, and for noise policy in general appeared on UK Government Department websites. The first of these was a project to undertake a review of research into the links between noise and health. This research has now been completed and the various reports can be viewed below. The report has been split into two reports with a project report giving some background information and a summary of the findings while the technical report goes into greater detail and is aimed at those with an expert interest in the subject. The 2009 report is available at http://archive.defra.gov.uk/environment/quality/noise/igcb/publications/healthreport.htm. In August 2010 . Defra followed up the 2009 report with their own, based on additional data being made available. This report builds on the evidence gathered in “Estimating dose-response relationships between noise exposure and human health in the UK” (2009) by UK noise experts and aims to build those findings into an appraisal. Based on the review, recommendations were made for how reflect the health impacts of noise in policy appraisals:

### HM Treasury

The above Defra report on “Noise & Health – Valuing the Human Health Impacts of Environmental Noise Exposure “, based on the report of July 2009, now forms part of the Government policy as indicated in The Treasury Green Book, which is HM Treasury guidance for Central Government, setting out a framework for the appraisal and evaluation of all policies, programmes and projects. It sets out the key stages in the development of a proposal from the articulation of the rationale for intervention and the setting of objectives, through to options appraisal and, eventually, implementation and evaluation. It describes how the economic, financial, social and environmental assessments of a proposal should be combined and aims to ensure consistency and transparency in the appraisal process throughout government.

See http://www.hm-treasury.gov.uk/data_greenbook_index.htm

NOISE POLICY STATEMENT FOR ENGLAND

In March 2010 Defra published The Noise Policy Statement for England [published on 15 March 2010] (see: http://www.defra.gov.uk/environment/quality/noise/npse/ ). This document sets out the long term vision of government noise policy to promote good health and a good quality of life through the management of noise. The policy represents an important step forward, by helping to ensure that noise issues are considered at the right time during the development of policy and decision making, and not in isolation. It highlights the underlying principles on noise management already found in existing legislation and guidance. The policy was developed in consultation with key partners within and outside of government.

NOISE ACTION PLANS

The purpose of Noise Action Plans is to assist in the management of environmental noise and its effects, including noise reduction if necessary, in the context of government policy on sustainable development. Noise Action Plans are based on the results of the strategic noise maps published in 2008. Responsibility for preparing noise maps and noise action plans for major airports (and smaller airports close to agglomerations) falls on the relevant airport operator. To date, the Secretary of State for Environment, Food and Rural Affairs has formally adopted Noise Action Plans for 23 agglomerations (large urban areas), major roads, and major railways in England as of 15 March 2010
(see: http://www.defra.gov.uk/environment/quality/noise/environmental-noise/action-plans/).

ACTIVITIES IN THE UNITED STATES OF AMERICA (USA)

There have been very little major improvements of modifications of U.S. noise policy since 2008, although each of the involved federal agencies, such as the Federal Aviation Administration, Department of Housing and Urban Development and the Department of Transportation, all continue to have active program on noise mitigation and most have active research programs. However, the first national program to examine how to improve U.S. noise policies, a new national program has recently been implemented, entitled “Towards a Quieter America”. This program will include a series of workshops, roundtables and briefings in Washington, DC throughout 2011. The primary basis for the broad national campaign was the 2010 publication of “Technology for a Quieter America” by the National Academy of Engineering.

ACTIVITIES BY THE INTERNATIONAL INSTITUTE OF NOISE CONTROL ENGINEERING

Although not a policy-making organization, in 2011 the International Institute of Noise Control Engineering (I-INCE) published the Final Report of Technical Study Group 6, entitled “Guidelines for Community Noise Impact Assessment and Mitigation”. This noise policy-related report addresses the major issues involved in performing environmental noise impact assessments and provides recommendations for a generic Environmental Noise Impact Assessment Process (EIAP), which is recommended for use around the world in a more harmonized manner.

## ACTIVITIES IN SWITZERLAND

Noise abatement is well established in the environmental policies of Switzerland. The policy to reduce or avoid noise exposure of the population was laid down in the Environmental Protection Law and in the Noise Abatement Ordinance in 1983 and 1987, respectively. The legal framework was further developed in the following years by introducing exposure limits for roads, railways, civil shooting ranges, industry and trade installations, civil and military airports as well as legal regulations for the Swiss railway noise remediation action plan.

Present situation: In the last years considerable efforts have been undertaken to prevent new noise problems and to remediate noisy installations. More than two billion Euros have been spent on action plans to make roads, streets and railways less noisy and at least another two billion Euros will be spent till the end of the remediation process in the 2020's. The legal framework has been further updated with health-evidence-based limit values for military shooting grounds and benefit-orientated subvention regulations to incite and accelerate the action plans of noise abatement of roads. Measured noise exposure maps on paper have been replaced by powerful calculation methods coupled with Geographical Information Systems (GIS) to handle huge quantities of spatial, demographic and infrastructure data. The introduction of a new national monitoring system SonBase made it possible to map noise exposure of the entire country with harmonized calculation methods and nationwide data. Results show that 1.3 million people or 17 % of the Swiss population are exposed to traffic noise levels above the legal limits. Taking the critical limits recommended by WHO the number rises even to 4 million people or more than 50 % of the population. The annual external costs of noise are estimated to be around 700 million Euros.

Future efforts are planned on the following topics: The noise monitoring system will be improved by enhancing the accuracy of input data such as GIS and traffic flow information and by making use of data available on a regional level. Additionally, research in risk assessment will be concentrated on updating the scientific basis for exposure-response functions, limit values and new valuation methods such as the DALY-concept in order to describe and quantify the impact of noise on public health and the economy. Noise abatement at source will be intensified by developing and enforcing silent innovative technologies such as low-noise appliances and vehicles as well as silent tires and pavements. Moreover, new economic incentive systems to reduce noise will be evaluated, including measures to increase market transparency (e.g. labeling low-noise products and areas) and polluter-pays based financing methods.

Harmonization of noise abatement in Europe will be tightened by intensifying international collaboration and exchange of information. In addition to the already existing working groups of the EU and the WHO, a new "Interest group on traffic noise abatement" under the Network of the Heads of Environment Protection Agencies was created in 2010. The aim of the group is to develop and recommend (practical) short term as well as (visionary) long term noise abatement solutions.

## ACTIVITIES IN AUSTRALIA

Noise policy in Australia is implemented at the State level and there are variations from State to State. However, the general approach remains the same namely to control the noise and to avoid creeping background noise levels. This can lead to complicated assessment both in terms of comparison with a background noise level and with a noise zone standard. There is also an acknowledgement that many developments need to go ahead and so there is an acceptance of reasonable and feasible measures along with community consultation. There are a number of issues arising in regard to noise impact from major infrastructure that is at a much greater scale that has previously been installed. Much of this is being driven by the needs for alternative energy sources. For example very large gas fired power stations have led to complaints about excessive very low frequency noise. The lack of clear guidance on assessment of such noise is a concern to the regulatory agencies. Similarly there is great concern in the community about the low frequency noise from wind farms. Large farms are proposed for the hill tops in rural areas and while only a few residents may be affected these are quite vocal.

Another concern for some agencies is the methods for establishing appropriate acceptable noise levels for residential areas within what has been commercial areas. In the past there has been separation of the two land use zones and any conflict has been only along the boundary. But there is a trend to increase the housing density with apartment buildings close to the commercial centre and often with commercial activities at street level.

## ACTIVITIES IN IRELAND

The transposition of EU Directive 2002/49/EC into Irish legislation has, for the first time, brought about a national strategy for the assessment (and control) of environmental noise in Ireland. Prior to the Directive, noise studies were limited and generally conducted on a case-by case basis, relying heavily on relevant UK guidance. However, in 2004, the NRA released their “Draft Guidelines for the Treatment of Noise and Vibration in National Road Schemes”. These guidelines radically changed the situation and provided explicit and relatively detailed guidance on how noise should be addressed during the preparation of an EIS. The guidelines refer to EU Directive 2002/49/EC and introduced the Lden indicator to noise assessments. They have since become a de facto standard for noise assessment in Ireland.

The first phase of noise mapping was successfully completed in 2007. This described the level of noise exposure of approximately 1.25 million people. The second phase, due to be completed in 2012, sees a significant increase on the extent of mapping required and as such, a large number of local authorities with no mapping experience will be involved in the process. It will be important to draw on the experience of the first phase in order to successfully deliver the strategic noise maps in 2012. To assist with the implementation of the second phase the EPA have released guidelines for noise mapping and action planning and Ireland has nominated an expert to sit on the CNOSSOS-EU Technical Committee preparing common European noise assessment methods. It is hoped that such methods will improve the reliability and comparability of noise mapping results across the EU.

## ACTIVITIES IN SWEDEN

In Sweden, traditionally, road pavements have been selected based essentially on the durability and resistance to wear by the tires, many of which in Sweden are equipped with steel studs in winter time. It means that the cost for the road authority has been minimized, and the road user and road environment costs have been more or less neglected.

However, presently the Swedish Transport Administration (STA) has a new and brave policy for selection of environmentally more friendly road pavements on trial. It is based on a cost/benefit comparison of the presently dominating Swedish pavement (SMA16) with some candidate pavement that is better from an environmental point of view. On the "cost side" is then the extra cost for laying and maintaining the candidate pavement compared to the "standard" Swedish pavement, which is SMA16. On the "benefit side" is then the monetary evaluation of the environmental improvements by the candidate pavement, as expected for

- lower noise exposure
- lower rolling resistance (converted to lower fuel consumption and less CO2 emissions)
- lower emission of particulates into the air

Some of these "benefits" may assume negative values, depending on the properties of the candidate pavement. If the overall result of the comparison shows a significant net benefit for the candidate pavement, the candidate pavement should be used instead of the "standard" and traditionally used pavement. The experience so far shows, for example, that

- on the "cost side" the wear caused by the studded tires in winter usually is very influential, but it depends on traffic volume and speeds

- the benefit of lower noise exposure may have large influence on the net result if the population density is high along the studied road section, but insignificant if the density is low

- the benefit of lower rolling resistance is often dominating the overall result, but is usually well correlated with favorable noise effects

- candidate pavements which often appear more favorable than the standard SMA16 are SMA:s with smaller aggregates (stones); typically 11 instead of 16 mm, or even 8 instead of 16 mm, also

- dense asphalt concrete pavements may appear to be more favorable despite much faster wear

Presently, the system is refined and new data are collected in order to obtain more accurate estimates of environmental effects and their monetary values. The policy is not yet applied everywhere but experience is collected and is expected later to result in a changed pavement selection policy nationwide, which will be beneficial to the entire road user and road environment, yet being economically justifiable in an overall sense.

## ACTIVITIES IN JAPAN

Activities in Japan over the past five years include revision of the “Environmental Impact Assessment Law”, designed to prevent serious influence on environment by large-scale developments. The Environmental Impact Assessment Law was enacted in 1997 in Japan. To strengthen this law, a minor amendment was made in April 2011, in which the concept of “strategic environmental assessment” has been included. According to this revision, wind turbine noise has been included as a subject of this law, although Japan still has noise policy issues to address, such as how to measure and assess this kind of noise, which has not been standardized and noise criteria have not been specified. Other activities in Japan include the following:

In the end of 2007, the guideline of Environmental Quality Standard (EQS) for Aircraft Noise was revised by the Ministry of the Environment to use Lden instead of WECPNL. Revision of a manual for measurement and evaluation of aircraft noise followed it in 2009. The guideline will be enforced from 2013, April.

Concerning the EQS for High-speed Railway (Shinkansen), the Ministry has not yet been successful in revising it to use $L_{Aeq}$-based metrics, nor in establishing an EQS for Conventional Railways. Thus, $L_{ASmax}$ is still used as noise index for Shinkansen. Japan has no guidelines for existing conventional railways except when a railway line is planned to be reformed on a large scale. The Ministry has been studying the way to land use planning, especially along railway lines, but has not yet established any final document.

Revision of the Aircraft Noise Prevention Law, et al. as the basis for environmental measures is now under progress by the Ministry of Land, Infrastructure and Transportation. Revision of another law for environmental measures around defense facilities will also follow these.

The ministry of the Environment performed a research project on the effects of noise on sleep disturbance by organizing a study committee, but it has not yet been successful in establishing a final method of evaluation.

Concerning Wind Turbine noise, the Ministry of the Environment has started an investigation on this topic since last year.

The Ministry of Defense has been studying whether it should revise the method of evaluation for effects of aircraft noise and artillery noise on educational facilities and hospitals, and so on.

Concerning product sound, there is a issue being considered for warning sound signal generation on electric cars.

## ACTIVITIES IN CANADA

"In 2010, Health Canada published a 1 page Notice to Stakeholders titled Noise from Machinery Intended for the Workplace. This document recommends that machinery, intended for the workplace be sold, leased or imported into Canada, with accompanying standardized noise emission declarations in both the technical sales literature and the instructions for use. The Notice refers to The Canadian Standards Association's (CSA) Standard Z107.58 Noise Emission Declarations for Machinery as well as the European Union (EU) Machinery Directive and numerous international standards supporting this EU Directive. In related activity, a Health Canada research scientist was project leader for the revision of the ISO 3740 series of standards for the determination of sound power using sound pressure measurements. Five of these ISO standards were published in 2010.

In the area of environmental noise, in 2010, Health Canada published a summary document titled "Useful Information for Environmental Assessments" which contains a Noise section. The more detailed guidance document on Noise is in preparation. Furthermore, since 2010, in collaboration with Canada's Provinces and Territories, Health Canada is in the process of developing National Guidelines for Wind Turbine Noise."

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# Health costs of noise: What have we learnt from the literature and their use in noise policy?

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ABSTRACT

Traffic, especially air traffic, is expected to increase in the future; consequently more people will likely face an increasing number of noise impact constraints. Therefore public authorities need an assessment tool of noise effects: noise costs. How these costs can be assessed and integrated in the policy making?

Within the FP7-ENNAH project (European Network on Noise and Health), a research work addressed the health costs of noise: current knowledge (preliminary overview of methods) and noise values derived from these costs, applied by researchers and policy makers.

For monetary assessment of noise impacts, various different studies were examined, where a wide range of real estate losses as well as loss of work and life were ascertained. It is assumed that the owner is aware of the disruption and annoyance caused by noise, which is not often the case for health effects.

First of all, a literature review related to health costs of noise in general and of aircraft noise in particular has been performed as well as ongoing research projects were taken into account.

Secondly, a survey was worked out for experts in this field. A short questionnaire was designed and then sent out to 58 experts involved in noise research and in noise policy, from Europe, Japan, USA and Australia. Their views about the practices and difficulties encountered, when assessing health costs of noise, will be presented and discussed here.

For assessing benefits of noise abatement policies, it is recommended to systematically use noise values reflecting health costs of noise.

# Development of a state planning policy for road and rail transport noise – the Western Australian experience

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## INTRODUCTION

Western Australia is the largest Australian State, occupying a land area about ten times that of the United Kingdom. With the rapid expansion of its mining industry and the urban development of its capital city, Perth, the State places great reliance on efficient road and rail transportation systems. It is well known that road and rail transport noise can cause significant amenity and health impacts on adjacent communities, and that poor land use planning can lead to encroachment by incompatible developments adjacent to transport corridors.

Effective planning policies are therefore central to the prevention and management of noise impacts; they must recognise both the state of research into the effects of noise on humans and the practicalities of constructing the urban landscape.

This paper traces the development of a whole-of-government planning policy for road and rail transport noise for Western Australia; describes the key features of the policy; and examines the experiences of the State environmental agency with the implementation of the policy through a range of projects.

## DEVELOPMENT OF THE POLICY

### Drivers for a State Government road and rail transport noise policy

One of the main drivers for development of a road and rail transport noise policy for Western Australia (WA) was a legislative change in 1996 requiring that some land use planning schemes be subject to environmental assessment by the Environmental Protection Authority (EPA) under the *Environmental Protection Act 1986*. As the EPA began work on a guidance document for road and rail transport noise, it became apparent that other State road and rail infrastructure agencies had their own noise policies, and that a whole-of-government approach was needed. This led to the formation in 1999 of a working group under the Infrastructure Coordinating Committee of the WA Planning Commission.

### Working group activities 1999-2005

The working group comprised representatives of the relevant State agencies including the environmental, planning and transport departments; the road and rail infrastructure providers; and local government. The first task was to develop recommended noise criteria, based on current research into the effects of noise on human health and amenity and on the policies in use in other jurisdictions.

The consultant's report (ERM 2000) reviewed the literature on community response to noise, sleep disturbance and metrics for noise; and considered the various criteria in use in other Australian States and in the United Kingdom, Canada and Hong Kong. Considering the policy needs for WA, the report recommended the following noise criteria for new infrastructure proposals:

$L_{Aeq(Day)}$ in the range 50-60 dBA, and $L_{Aeq(Night)}$ in the range 45-55 dBA.

Day would be from 6 am-10 pm and Night from 10 pm-6 am, and the noise level would be assessed at ground floor level. The planning horizon would be 15 to 20 years.

For new noise-sensitive developments near existing transportation, ERM recommended adoption of the approach used in the EPA preliminary draft Guidance No.14, which provided a set of acceptable and conditional land uses for a range of noise environments (Macpherson 2000).

The second stage of the work involved testing various noise criteria levels against a series of road and rail transport scenarios, to assess the feasibility of adopting a particular noise criterion (Lloyd Acoustics 2003). The study was based on modeled noise levels for each scenario, with and without noise barriers, over various buffer distances and including both ground floor, first floor and second floor receivers. The study estimated the costs of noise barriers up to 5 m high that would be needed to achieve the upper and lower bound level noise criteria from the ERM study of 2000.

In summary, the study found that the lower bound noise criteria were likely to prove impracticable for new infrastructure to achieve, given the cost and height of noise barriers or the buffer distances required. The study found that the upper bound noise criteria should be practicably achievable for new infrastructure, and that noise levels between the upper and lower bounds could be achieved in some, but not all, cases.

Following this work, a draft Statement of Planning Policy: Road and Rail Transport Noise ('2005 draft policy') was prepared and released for public comment in 2005 (WAPC 2005a). The 2005 draft policy incorporated the criteria shown in Table 1.

**Table 1:** External noise exposure criteria in 2005 draft policy

| **Time Period** | **Exposure level 1 (Target), dB** | **Exposure level 2, dB** | **Exposure level 3, dB** |
|---|---|---|---|
| Day<br>6.00 a.m. – 10.00 p.m. | Less than $L_{Aeq}$ 55 | $L_{Aeq}$ 55-60 | Above $L_{Aeq}$ 60 |
| Night<br>10.00 p.m. – 6.00 a.m. | Less than $L_{Aeq}$ 50 | $L_{Aeq}$ 50-55 | Above $L_{Aeq}$ 55 |
| Additional criteria for railways | Less than $L_{A\,Max}$ 75 | $L_{A\,Max}$ 75-80 | Above $L_{A\,Max}$ 80 |

Noise levels would apply at 1 m from the most exposed façade and at 1.5 m above ground level, based on a 20-year forecast. No action would be required for noise levels in Exposure Level 1. For Exposure Level 2, new noise-sensitive development and new road and rail infrastructure proposals would be designed to meet Exposure Level 1 where practicable. Noise reduction measures would be mandatory in Exposure Level 3, with the objective of achieving Exposure Level 2 or better.

**Working group activities 2006-2009**

Following the public comment period on the draft policy, the working group began development of a final policy, in consultation with major stakeholders in the freight and housing industries. In 2008, a decision was made to amalgamate the 2005 draft policy with the draft Metropolitan Freight Strategy (WAPC 2005b), which had been released for comment at the same time as the draft noise policy.

Finally, State Planning Policy 5.4 Road and Rail Transport Noise and Freight Considerations in Land Use Planning (‘SPP5.4’, or ‘the Policy’), was published in the WA *Government Gazette* on 22 September 2009 (WAPC 2009a).

STATE PLANNING POLICY 5.4

### Status, scope and objectives

SPP5.4 is a State Planning Policy under the *Planning and Development Act 2005*, and applies throughout the State of Western Australia. It is administered by the WA Planning Commission in respect of new noise-sensitive land use developments, and is referred to by the EPA in assessments of infrastructure proposals. The key objectives of the Policy are (in summary) to protect people from unreasonable levels of transport noise through a standardised set of assessment criteria; to protect major transport corridors and freight operations from incompatible urban encroachment; to encourage best-practice design and construction standards for new developments; and to facilitate the development and operation of an efficient freight network.

The Policy scope covers proposals for (a) new noise-sensitive development in the vicinity of an existing or future major road, rail or freight handling facility; (b) new major road or rail infrastructure; (c) major redevelopment of existing major road or rail infrastructure; and (d) new freight handling facilities in the vicinity of existing or proposed future noise-sensitive areas.

The Policy is applied over a 15-20 year transport planning horizon.

The Policy does not apply retrospectively to existing roads and railways near existing noise-sensitive areas, nor does it apply to proposals involving an increase in traffic along an existing corridor in the absence of a major redevelopment. The Policy does not apply to other forms of transport, to safety warning devices installed on road or rail vehicles, to fixed noise sources, or to construction noise. While the Policy does not apply to ground vibration, it does provide some informative guidance.

### Noise criteria

Table 2 sets out the noise criteria applying to proposals for new noise-sensitive development and new major roads and railways under the Policy.

**Table 2:** Outdoor noise criteria under SPP5.4

| Time of day | Noise Target | Noise Limit |
|---|---|---|
| Day (6 a.m.–10 p.m.) | $L_{Aeq(Day)}$ = 55 dBA | $L_{Aeq(Day)}$ = 60 dBA |
| Night (10 p.m.–6 a.m. | $L_{Aeq(Night)}$ = 50 dBA | $L_{Aeq(Night)}$ = 55 dBA |

The criteria in Table 2 apply to noise when received at 1 m from the most exposed, habitable façade of the building receiving the noise. For new road or rail infrastructure proposals, the criteria apply at ground floor level only; while for new noise-sensitive development proposals, the criteria apply at each floor level, and within at least one outdoor living area on each residential lot.

The 5 dB difference between the ‘target’ and ‘limit’ criteria is described in the Policy as an ‘acceptable margin for compliance’ – it should be practicable to achieve noise levels within the ‘margin’ in most situations, however there is an expectation that in greenfields sites the ‘target’ should ultimately be achieved. Where noise levels are likely to exceed the ‘target’ the proponent should implement noise mitigation measures with a view to achieving the ‘target’; and where the noise levels are likely to exceed the ‘limit’ the proponent should implement mitigation measures to achieve the ‘target’, or if this is not practicable, noise levels within the ‘margin’.

Where it is not practicable to achieve the ‘target’ for new residential developments, the development should be designed to achieve an indoor $L_{Aeq(Day)}$ = 40 dB in living and work areas, and $L_{Aeq(Night)}$ = 35 dB in sleeping areas. The Policy refers to Australian Standard 2107:2000 for acceptable indoor design criteria for other types of noise-sensitive developments (Standards Australia 2000).

In the case of a proposal where neither the urban development nor the road/railway exists, the infrastructure provider and the land developer are required to engage in dialogue ‘to develop a noise management plan to ascertain individual responsibilities, cost sharing arrangements and construction time frame’.

The Policy states that ‘the noise criteria take into account the considerable body of research into the effects of noise on humans, particularly community annoyance, sleep disturbance, long term effects on cardiovascular health, effects on children’s learning performance, and impacts on vulnerable groups such as children and the elderly’, and makes specific reference to the World Health Organisation *Night Noise Guidelines for Europe* (WHO 2009).

While the $L_{Aeq}$ values for Night and Day remain the same as in the 2005 draft policy, the $L_{Amax}$ values for railways in the 2005 draft policy were deleted in order to simplify the criteria in the Policy. $L_{Amax}$ levels are more critical than $L_{Aeq}$ levels when the traffic stream contains low numbers of noisy events. The removal of the $L_{Amax}$ criteria was addressed by requiring that freight rail assessments include at least one train per hour, above which level the $L_{Aeq}$ criteria tend to dominate.

### Proposals for road and rail corridor redevelopments and new freight handling facilities

The criteria in Table 2 do not apply to redevelopment proposals for roads or railways, nor do they apply to freight handling facilities; instead the Policy adopts a ‘best practical means’ approach, involving a noise assessment and development of a noise management plan (NMP) for the project, in consultation with the Department of Environment and Conservation (DEC) and the local government. Noise mitigation measures are to be considered having regard to existing transport noise levels; likely changes in noise levels resulting from the project; and the potential for amelioration given the nature and scale of the works.

### Implementation

In the case of urban development proposals, the policy is implemented through various planning schemes and through decision-making on rezoning, structure plans and subdivision and development applications. These processes are conducted by the WA Planning Commission, in cooperation with local governments. Outcomes are achieved through approval conditions requiring preparation and implementation of a NMP and notifications on land titles.

Transport infrastructure proposals are subject to the environmental impact assessment process under the WA *Environmental Protection Act 1986*, where the assessment is conducted by the EPA, with technical advice provided by DEC. For these assessments the EPA would expect that the proponent will design the project to comply with the Policy. Again, the desired outcomes would be achieved through preparation and implementation of a NMP.

**Policy implementation guidelines**

The Implementation Guidelines for SPP5.4 is a comprehensive document providing guidance on noise assessment; strategies for managing noise impacts; and the use of planning mechanisms (WAPC 2009b).

The Guidelines identify two levels of noise assessment: screening assessment and detailed assessment. The former is a simple assessment based only on the type of transport corridor, estimated traffic flow in 15-20 years' time, and the distance from the corridor. Where a screening assessment indicates that the noise 'limit' is likely to be exceeded a detailed assessment is needed, and here the Guidelines provide comprehensive guidance on noise measurement and prediction methodology.

The Guidelines also provide practical guidance on the primary strategies for managing noise impacts, covering such topics as noise-compatible land-use planning, road and rail infrastructure design, transport noise barriers and bunds, and 'Quiet House' design. The Guidelines include two 'deemed-to-comply' noise insulation packages designed to meet the indoor noise criteria and the noise 'target' for an outdoor area: Package A where noise levels are in the 'margin'; and Package B where noise levels are within 3 dB above the 'limit'.

EXPERIENCE WITH IMPLEMENTATION OF THE POLICY

The following presents an overview of the author's experiences with the implementation of the Policy thus far.

**New infrastructure proposals**

The Policy (or its drafts) has been used in the environmental assessment of several major infrastructure proposals in the past few years. Three of these – a new urban passenger railway, a major highway and a freight railway – are discussed below.

The *Southern Suburbs Railway* project involved construction of a 71 km urban passenger railway from the center of Perth to Mandurah, a growing urban center to the south. The railway passes through a tunnel under the city center, then along the center of the Kwinana Freeway before deviating from the Freeway to pass through a series of new suburban areas on its way to Mandurah. The railway was opened at the end of 2007.

The project was designed to meet the noise criteria in the 2005 draft Policy. As the volume of rail traffic is much greater during the Day period than at Night, the $L_{Aeq(Day)}$ noise levels were typically at least 10 dB above the $L_{Aeq(Night)}$ levels, thus the Day criteria were the more critical. Noise modelling (not including the tunnel) indicated that the resulting noise levels would be in the 'margin' in a number of areas. Following consultation with community groups and DEC, the proponent developed a NMP involving construction of some 6.2 km of noise barriers, ranging in height from 1.5 m to 3 m. The post-construction monitoring at 22 locations confirmed that the objectives had been met (Lloyd George Acoustics 2008). Some 45 noise complaints were recorded on the Public Transport Authority database (unpublished) over about the first month of operation. Of the 35 individual complainants, 19 mentioned noise generally, eight mentioned wheel squeal and six late/early hours, while 12 mentioned ground vibration. Few complaints have been made in recent months.

Several observations can be made when considering the outcomes of the Southern Suburbs Railway project in relation to the current Policy. Firstly, the use of the noise criteria in the 2005 draft policy (equivalent to those in the Policy) appears to have led to a reasonable balance between preserving noise and visual amenity, and the requirements for noise barriers. This observation is however based only on noise complaint data, and a more complete picture would require a community survey. Secondly, this project raised the issue of regenerated noise resulting from the underground tunnel which is not addressed in the Policy; criteria were developed for the project based on other projects in Australia. Thirdly, with respect to ground vibration the Policy provides informative guidance only. Ground vibration was predicted to be a potential issue in six suburban areas with residences within 39 m of the Southern Suburbs Railway, and vibration matting was ultimately installed over a length of about 1 km of the railway in the most critical area.

The *Forrest Highway* project involved construction of an extension to the Kwinana Freeway to the south of Perth to meet up with the South-West Highway at a point some 60 km north of Bunbury, the gateway city for the south-west of WA. The noise predictions were again based on the $L_{Aeq(Day)}$ and $L_{Aeq(Night)}$ criteria in the 2005 draft policy. In this case the $L_{Aeq(Day)}$ noise levels were predicted to be just over 5 dB above the $L_{Aeq(Night)}$ noise levels, and the Day criteria were treated as the more critical.

The noise predictions indicated that future noise levels would exceed the 'target' for residences within about 200 m of the road (Lloyd George Acoustics 2006). Where noise levels were predicted to exceed the 'limit', noise levels in the 'margin' were achievable with a combination of a quieter road surface (in the more populated areas) and noise barriers up to about 3.5 m high. In many of these cases achieving the 'target' was considered to be impracticable, and the optimum selection of noise barriers was determined through public consultation and detailed negotiations between DEC and the proponent using a basic cost-benefit model. The proponent ultimately constructed 21 km of noise barriers at a cost of some $10 m; the noise 'limit' was achieved in all areas, with many locations receiving noise levels in the middle of the 'margin'. Some of the more isolated residences in the rural areas were provided with noise insulation in preference to noise barriers.

After completion of the road in September 2009 complaints were made by a number of residents regarding early morning truck traffic, generally associated with transport of goods to the city markets. The results of the post-construction noise monitoring indicated (8-hour) Night noise levels typically in the range 45-50 $dBL_{Aeq}$. The monitoring indicated that the Policy objectives were being met in all but a few cases, where some additional measures were needed. The question arises whether an 8-hour average Night noise level adequately addresses noise impacts where there is a 'bump' in the heavy traffic in the early morning hours.

The *Oakajee Rail* project is a proposed new freight railway over some 570 km from the new iron ore mining areas of the Mid-West region of WA to the proposed Oakajee Port to be constructed to the north of Geraldton, some 450 km north of Perth. The railway is in effect a 'greenfields' project that would pass through rural areas, carrying up to 18 trains per day of up to 2.2 km in length, operating on a 24-hour cycle.

As the noise levels would be similar during the Day and Night periods, the Night criteria are the more critical. The noise predictions indicated that the 'target' would be exceeded at 11 rural homesteads and the 'limit' at six of these (EPA 2011). However, the predictions also indicated that a further 37 homesteads may experience Night noise levels in the range 46-50 $dBL_{Aeq}$, where the impacts may also be significant, given the quiet rural nature of the area. As a result the EPA recommended that the proponent submit a noise mitigation and consultation procedure for residences where noise is likely to exceed an $L_{Aeq(Night)}$ noise level of 45 dB. Given the isolated nature of the homesteads in this area, noise amelioration is likely to take the form of noise insulation rather than noise barriers.

The observation can be made here that consideration could be given to the Policy better recognising the potential for noise impacts in quiet rural areas at night.

### Redeveloped infrastructure proposals

The major redevelopment proposals in recent years have involved roads. As the Policy does not set noise criteria for these proposals, reasonable outcomes have been able to be negotiated between Main Roads WA and DEC. In one case, where the existing road was to be virtually reconstructed, the criteria in the Policy were accepted as being achievable. In the other cases, a NMP was developed through a consultation process, to identify best practicable noise mitigation measures.

The observation that can be made here is that further experience of a range of redevelopment projects is needed before the Policy can be expected to incorporate specific noise criteria or mitigation measures.

### Noise-sensitive land use development proposals

Since the commencement of the Policy the author has provided technical advice on some 15 residential land use development proposals. As a general observation the Policy has stood up well when challenged through the planning process and in the mediation process of the WA State Administration Tribunal.

The following observations can be made from these projects. Firstly, while some land developers have been initially unwilling to undertake noise studies and develop NMPs, once a noise study has been conducted the issues tend to be effectively clarified and addressed under the Policy. Secondly, some developers are not keen on an urban form that includes noise walls (for visual and security reasons), instead preferring noise insulation of the dwellings; however this approach does not always provide protection for outdoor recreational areas. Thirdly, the wording of the conditions of planning approval is considered critical if the measures in the NMP are to be communicated to the land purchaser and implemented effectively.

## REVIEW OF THE POLICY

The Policy states that a two-year review of its operation and effectiveness is expected to be conducted. The above analysis suggests that the issues to be addressed in the review may include the following:

- Do the current noise criteria achieve the best balance between protecting health and amenity and being practicable for proponents to achieve?

- Should the Policy present noise criteria for areas that are presently missing: recreational areas, regenerated noise from tunnels, major infrastructure redevelopments, freight handling facilities, and rural areas where noise levels are below the target?
- Should the policy address ground vibration from railways?
- What further work is needed to assess community and stakeholder acceptance of the Policy outcomes?

## CONCLUSIONS

For the first time, WA has an integrated planning policy for road and rail transport noise that contains noise criteria and implementation measures for both new noise-sensitive developments and new or upgraded infrastructure. The Policy seeks to provide a good balance between protection of the health and amenity of the community versus the practicalities of constructing the urban landscape.

Experience with the application of the Policy indicates that the Policy objectives are being or can be met in the projects that have been assessed to date. A number of areas can be identified in which the Policy and its accompanying Guidelines could potentially be improved, and it is expected that the forthcoming two-year review may address these issues.

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# A meta-analysis of stated preference studies of noise nuisance

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## INTRODUCTION

This paper first provides a brief overview of developments in the valuation of noise nuisance. The challenge of obtaining economic values of noise nuisance has led to an increasing application of stated preference methodologies in recent years. The vast majority of these studies have been in the context of aircraft or road traffic noise nuisance and values obtained exhibit a high degree of variation. It is possible to speculate that these differences could be a result of variation in experimental design and implementation or due to the systematic influence of particular variables.

The main aim of this paper is to provide a rigorous analysis of the available studies through a meta-analysis that should provide insight into the causes of the variation in values and may allow us to alight on a recommended value (or values) derived from this approach.

Issues to be examined from a theoretical, methodological and empirical standpoint include: the context where the noise is experienced; the source of the noise; the representation of noise levels to respondents; the framing of questions in terms of both gains and losses and willingness to pay or willingness to accept; the scale of the changes offered; the time period for noise reduction and the time period for payment; the type of stated preference experiment used; the extent to which data is manipulated or trimmed; segmentation by income; annoyance or other factors with some commonality between studies; the models applied and other issues that may emerge.

## NOISE VALUATION CONTEXT

As there is no market for quiet, the classic approach to valuing noise nuisance has been to seek a market within which noise is implicitly valued. If people have a value for quiet then intuitively this would be manifested in a willingness to pay more for houses in quieter areas and conversely less for homes in noisier areas. Typically, then use is made of the housing market where price is a function of a bundle of characteristics of the house and the neighborhood including noise. The value of noise obtained is normally expressed in the form of a Noise Depreciation Index (NDI) or Noise Sensitivity Depreciation Index (NSDI) which indicates the percentage change in house prices that results from a 1 dB change in noise levels. Detailed exposition of the theory and method may be found in Baranzini et al. (2008).

The quantity of hedonic pricing (HP) studies on aircraft noise is such that a number of meta-analyses have been carried out. The most recent by Wadud (2010) included 53 estimates of house price depreciation from aircraft noise concluding that a 1 dBA change in aircraft noise levels leads to a fall in house prices of between 0.45 % and 0.64 %. This estimate is broadly consistent with earlier analysis by Nelson (2004) and the early review by Nelson (1980) though somewhat lower than the estimates of Schipper et al. (1998) of 0.9 % to 1.3 %. There are fewer studies of road traffic noise and no formal analyses have been conducted. Bateman et al. (2001) reviewed 18 studies of road traffic noise mostly from North America finding an average NSDI of 0.55 %. This value is somewhat higher than the 0.40 % identified by Nelson (1982) from nine studies and 14 values all from Canada and the USA. Although the average values are broadly consistent the range of original values is large.

The HP method is attractive because it has a basis in real decisions in the market place and values may be linked to measured or modeled noise levels. However, it may be criticized in that purchasers may not have perfect knowledge of all the attributes of all the houses in their choice set; the housing market is susceptible to other imperfections, most notably transaction costs; explanatory variables suffer from correlation and it is difficult to measure some intangible influences and perceptions of them. HP is also limited in that it can only give a value of disturbance as experienced at home. Additionally the measures of noise used are often quite crude contours. Meta-analysis suggests that this cost may be capitalized through a house price discount of about 0.5 % to 0.6 % per dBA. In order to convert this to a value per dBA per year assumptions must be made about house purchaser's discount rates and the time period over which the values should be discounted. Even then the method cannot tell us what people might be willing to pay now for changes in the noise level experienced or how this might vary by time of day, day of week or season. These are interesting policy questions and for answers another approach was needed.

Stated preference methods (SP) are essentially hypothetical questioning techniques. There are two main forms: Contingent Valuation Method (CVM) and Stated Choice (SC). CVM has a long history in environmental economics whilst SC was more common in other areas including market research and transport studies, SC methods are now being adopted in environmental economics. They offer certain advantages over HP techniques. Firstly, control over the experimental conditions which can ensure: avoidance of correlation between independent variables; sufficient variation in attribute levels; better trade-offs than might exist in the real world; investigation of levels of noise or quiet outside current experience; design can ensure that secondary variables are not dominated; avoidance of measurement error in the independent variables; the ability to "design out" variables by specifying them to be the same for each choice. Secondly, it enables disaggregate analysis relating to individual characteristics but also variation by for example by time period. Thirdly, multiple observations are obtained for each person allowing more precise estimation. Hence, the growing interest in applying such techniques to noise nuisance. The number of studies available is now such as to lend itself to the application of meta-analysis that will hopefully provide insight into the variation in noise values obtained by such studies.

## WHY META-ANALYSIS?

Meta-analysis utilizes data from a number of studies to attempt to explain variation in the values of the factor of interest here the value of noise reductions or increases in terms of socio-economic and study specific variables. Key advantages of such an approach are outlined by Abrantes & Wardman (2011) and Nelson & Kennedy (2009) those of most relevance in this context are:

- To provide guidance on "preferred" values, drawing on numerous sources rather than depending on a single study.
- To explain what determines between (and within) study variation. Instead of simply taking a mean value, meta-analysis seeks to identify the variables that

explain such variation. Where these are methodological this may suggest ways of improving future empirical studies.

- To explore aspects such as spatial or temporal variation which are beyond the scope of a single study.

In his 2002 review Navrud concluded that there were still too few SP studies for such analysis. In 2011 this situation has changed, we have identified around 60 such studies covering transportation noise. The aim in sourcing studies was to be as inclusive as possible identifying studies in the grey and academic literature. The current data set contains 252 values from 44 studies across 22 countries. This is still an evolving set of data and we expect to incorporate values from at least 3 or 4 more studies before the data set is finalized – thus the simple models reported here are highly exploratory in nature.

META-ANALYSIS CHALLENGES AND DATA

Key challenges in assembling an appropriate data set were as follows:

- Defining the dependent variable – SP studies tend to value a subjective measure of change in levels of noise or annoyance which varies a great deal between studies.
- Different contexts, not just in the source of the noise but also the location where it is experienced, though the vast majority of studies assess in-home nuisance, several examine noise during a journey.
- Study methodologies, not simply between stated choice and contingent valuation methods, but significant variation within each method, particularly with respect to the treatment of cost.
- Range of study years and countries. The earliest data is from 1968 and the most recent from 2009, a span exceeding 40 years. To date we have data from 22 countries. Standardizing values again poses a challenge.
- Identifying study attributes that are expected to influence the value of noise, ranging from socio-economic factors such as income through to study design features that may induce bias or difference, such as, transparency of design, is it obvious that noise is the focus of the study?, whether the questions are couched in terms of willingness to pay or willingness to accept and similarly, though not identically whether the scenario proposed represents a gain or a loss.

**Defining the dependent variable**

Studies use of a wide range of methods to present a change in noise levels to respondents. In order to be of greatest use in identifying the value of an objective noise measure the dependent variable here is defined as the annual value placed on a change of one decibel. As few studies report such a value this has required the use of a range of assumptions to convert values expressed in different subjective forms to a decibel value. These assumptions form part of the data set and will be tested for their influence, if any, on the value of noise. These are as follows:

- Where the study adopts assumptions to derive a decibel value these are applied.

- Where a proxy allows a reasonable estimate of the objective change in noise levels to be made, this is used.
- Where a change represents a halving of noise levels a change of 8 dBA is assumed and where a change represents a removal of noise annoyance a change of 10 dBA is used. These two assumptions follow Navrud (2002).

**Study year and country**

Values need to be converted to a standardized currency and year. Here we have uplifted all values to 2009 using the Consumer Price Index for the study country. These values are then converted to 2009 $US using official exchange rates for 2009 (World Bank 2010). We have deliberately avoided updating the values to allow for growth in incomes over time as income will be used as an independent variable. This is a critical area of interest in indicating a link between income growth and growth in the value of quiet. Cross sectional studies suggest that this elasticity is less than one but there is little consensus on the precise relationship (Bristow 2010).

**Study contexts and explanatory variables**

The majority of studies address noise nuisance experienced at home. Since few studies provide income segmentations or even average incomes of respondents, we therefore use per capita Gross Domestic Product as a proxy. Most of the defined variables relate to study methodology and include:

- Basic descriptive information relating to publication year, study year, type of publication, country and sample size.
- Basic information on method: stated choice or Contingent valuation or other; method by which noise is represented, context, noise source, time period when noise is changed.
- More specific information on method including: who pays; transparency, willingness to pay (WTP) or willingness to accept (WTA); gain or loss for CVM the type of cost presentation and whether zeros or extremes are trimmed; payment vehicle and time period for payment and where appropriate the largest change in cost offered.
- Information on any noise measurement or modeling.
- Some studies segment values by key attributes, for example annoyance level or income these are included here.

INITIAL MODELS

The initial models were run with the log of the per dBA value as the dependent variable. This means that the coefficients of variables expressed in logarithmic form denote elasticities, representing the proportionate change in valuation after a proportionate change in the variable in question, whereas the coefficients of dummy variables when exponentiated indicate the proportionate change in value from being at that level of a variable relative to the omitted category.

The initial tests included dummies for: method (CVM, SC); source of the noise (air, road, rail, combined); log GDP; payment period (weekly, monthly, annual, perjourney and house price); context (home, journey); combinations of WTP/WTA and gain and loss; was the noise change measured in the study or estimated (real; estimated in study; estimated for analysis); was the purpose transparent or not; presentation of noise; type of CVM relative to SC; type of publication; type of survey; whether CVM data had been trimmed or not and finally how zeroes had been treated in CVM. Variables that were not significant at 90 % were removed one by one and levels combined where appropriate (note that sets of dummies are retained where one or more is significant and there is no logical case for merging insignificant variables). Unfortunately the dummy variables defined for type of CVM and to a lesser extent presentation had a number of levels that were study specific and have been dropped for this reason. The next step in the modeling process will be to allow effectively for study specific and random effects. It is possible that these may be the dominant effects. A model run solely on study dummies indicated that many were significant. At this early stage we report a simple regression based a number of key potential explanatory variables excluding study effects, see Table 1. Variables not significant at 95 % are indicated in italics.

**Table 1:** Exploratory Regression Model (dependent variable = log of value per year for a change of 1 decibel, in US$2009)

| Variable | Coefficient | T-statistic | Effect or elasticity |
|---|---|---|---|
| **Constant** | 1.921 | 3.632 | |
| **Method** | | | |
| SC | Base | Base | |
| CVM | -1.030 | -4.016 | -64 % |
| **Log GDP** | 0.341 | 2.767 | 0.341 |
| **Noise source** | | | |
| Road traffic | Base | Base | |
| Air | 1.045 | 4.851 | +184 % |
| Rail | -0.579 | -2.713 | -44 % |
| *Combined source* | *0.832* | *1.174* | *+130 %* |
| **Payment period** | | | |
| Annual | Base | Base | |
| Monthly | 0.597 | 2.558 | +82 % |
| Weekly | 1.556 | 4.821 | +374 % |
| *Per journey* | *-0.388* | *-0.662* | *-32 %* |
| Houseprice | 2.815 | 5.716 | +1569 % |
| **Gain/loss and WTP/WTA** | | | |
| WTP for a gain | Base | Base | |
| *WTP to accept a loss* | *0.445* | *1.003* | *+56 %* |
| *WTA to forgo a gain* | *-0.177* | *-0.262* | *-16 %* |
| WTA to compensate for a loss | 1.707 | 5.284 | +451 % |
| *Both combined in one model* | *0.558* | *1.524* | *+75 %* |
| Neither (WTA for current) | 2.011 | 3.108 | +647 % |
| **dBA real or estimated** | | | |
| dBA estimated | Base | Base | |
| dBA estimated within study | 0.786 | 2.126 | +119 % |
| *dBA real* | *-0.347* | *-1.702* | *-29 %* |
| Adjusted $R^2$ sample size | 0.652 | 252 | |

This preliminary model has a respectable adjusted $R^2$ explaining variation in the data well. The negative and significant coefficient on CVM indicates that these studies yield values 64 % lower than SC studies. There is some supportive within study evidence from seven studies that open ended CVM provides lower or similar range values than SC (Bristow 2010).

A key finding is that the elasticity of values to income is 0.341 this is in line with values estimated in individual cross sectional studies (Bristow 2010), but on the low side when compared with evidence on other factors such as the value of time where there is no reason to expect a diversion from a unitary effect.

The values with respect to noise source indicate higher values for aviation noise and lower values for rail noise compared to road. This finding is in line with the weight of evidence in annoyance studies which indicates that a given measured level of noise is more or less annoying depending on the source. Aviation noise is most annoying, rail noise the least annoying with road lying somewhere in between (Miedema & Oudshoorn 2001).

With respect to the payment period the overall value falls with the time period for payment – so if people are asked to pay weekly their value is higher than if asked for an annual payment. This may be influenced by the range of values offered within studies. It also appears that where a payment is rolled up into the house price the value is much higher, this maybe because it represents a relatively small proportion of the whole or because the likelihood of payment is remote or a reflection of the small number of studies using this payment mechanism.

Another key finding is that with respect to whether respondents are asked to pay or accept compensation and whether this is for a gain or a loss. The most common formats are WTP for a gain and WTA compensation for a loss. If WTP for a gain is the base then WTA for a loss yields higher values as does the special case of WTA compensation for the current situation the rest are not significantly different from WTP for a gain. Although the difference looks very large with WTA values being five and a half times the WTP values, the review by Horowitz & McConnell (2002) found WTA values to be ten times higher across 46 studies of goods without a market price. The key difference is in the WTP or WTA framing as only the WTA a loss is significantly different from the other formulations rather than a difference in the valuation of gains and losses. This has also been identified within studies (Wardman & Bristow 2008).

It appears that where the change in decibels is estimated whether within study or for this analysis the value is higher than where a measured change in noise levels is used.

As stated above this is a very preliminary analysis and whilst the initial findings are of interest a more sophisticated approach will be required to see if these effects are stable once any additional explanatory variables are considered and individual study effects and random effects are allowed for. The next step will be to test random parameters on the constant to allow for varying constants (ie values) across studies.

## CONCLUSIONS

We are constructing a large data base of noise valuation studies using CVM and SC techniques. At present it is difficult to draw firm conclusions on the key explanatory variables. However across model iterations we found that the GDP and WTP/WTA effects remained broadly consistent. Whilst findings may be related to study specific attributes and clearly require further analysis, where within study evidence exists it is broadly supportive.

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# An update on research to guide United States policy on aircraft noise impact

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## INTRODUCTION

Aircraft noise is a major environmental concern and can constrain aviation growth. Over several decades, United States policy has promoted actions to reduce the impact of aircraft noise on people around airports. The number of Americans living in areas of significant aircraft noise exposure has been reduced from 7 million in the mid-1970’s to less than 300,000. Looking forward, the goal is to continue to reduce people exposed to significant noise despite aviation growth, and provide additional measures to protect public health and welfare and national resources (e.g., national parks). Measures to reduce noise impact—including aircraft source noise reduction, noise abatement flight procedures, airport configuration changes, land use controls, funding for noise mitigation—are guided by the level of the cumulative noise impact using the Day-Night average sound Level (DNL) and whether land uses are deemed incompatible with that level. Determinations rely on studies that were last reexamined in the U.S. in the early 1990’s. There have been changes in aircraft technology, operations, public expectations, and scientific knowledge. New software tools under development will have the capability to quantify interdependencies among aviation-related noise, emissions and fuel burn both at the source level and through changes in health and welfare endpoints.

This paper provides a synthesized review of major considerations related to aircraft noise impact and research being conducted to guide U.S. policy.

## AVIATION NOISE IMPACTS ROADMAP

In 2009, the Federal Aviation Administration (FAA) Office of Environment and Energy began the process of developing a comprehensive research roadmap to address noise impact research needs (Girvin 2009). In 2009-2010, the FAA conducted three workshops focused on noise impacts on health, annoyance, and sleep disturbance. During the workshops, the knowledge gaps were discussed and research projects were proposed to address the gaps. Following recommendations from experts in the field, the FAA funded several studies on the relationship of noise to annoyance and sleep disturbance, which are described in this paper. Workshop attendees expressed an interest in conducting regular meetings to coordinate and communicate research activities and findings, advance collective scientific knowledge, and develop optimal mitigation solutions.

The first Meeting on the Aviation Noise Impacts Roadmap was held in April 2011 in Washington DC. The FAA, National Aeronautics and Space Administration (NASA), Department of Defense (DoD), Department of Housing and Urban Development, National Park Service, Centers for Disease Control and Prevention, National Institutes of Health, National Oceanic and Atmospheric Administration and other federal agencies, international organizations, industry, academia, and the public met to discuss ongoing activities and future noise impacts research needs. Based on presented material, discussion and responses to knowledge gaps questionnaires, the Aviation

Noise Impacts Roadmap will be developed and posted on the FAA website. The roadmap will outline key research elements, summarize current programs and projects, identify knowledge gaps, and future research activities.

## CURRENT FAA SPONSORED NOISE RESEARCH

The noise research framework is grounded in understanding the problem and developing solutions (Girvin 2008). There are four key focus areas: noise effects on health and welfare, aircraft noise modeling, costs of aircraft noise on society, and noise in national parks and wilderness.

### Noise effects on health and welfare

The current criterion of DNL 65 dB as a threshold for significant noise impact was established in 1980. In 1992, the Federal Interagency Committee On Noise (FICON) reviewed and reaffirmed DNL as the best noise exposure metric and endorsed the dose-response relationship to determine community noise impacts, with broad acceptance of 65 dB as a reasonable criterion. These determinations rely on studies that were last reexamined in the U.S. in the early 1990's. Since that time, there have been changes in aircraft technology, operations, public expectations, and scientific knowledge. In addition, the majority (more than 95 %) of all social surveys of reaction to noise after the 1970s were conducted overseas (Bassarab et al. 2009) and may not be reflective of the U.S. experience. In short, it is time to revisit the foundations on which the criterion has been established.

The experts and other attendees at the 2009-2010 workshops identified five high priority research project topics on annoyance and eight on sleep disturbance. The topics on annoyance include: a review of available studies, the conduct of new surveys in U.S., the retrospective study of community reactions, the development of a standardized noise complaint handling system, and test methods for communicating with the public on aircraft noise. The identified research interests on sleep disturbance include: meta-studies of reports of sleep disturbance, the comparison of sleep disturbance studies of U.S. populations with other populations, the comparison of sleep disturbance models and prediction results for realistic scenarios of an entire night of operations, the review of studies of next-day effects, the review of studies to identify populations that experienced variable nighttime exposures and to separate effects by exposure, the use of available sleep disturbance models to compare awakenings with corresponding values of $L_{night}$, the examination of available non-sleep disturbance studies of health effects for applicability to disturbances produced by noise, and collaboration with the National Institutes of Health to determine whether previous or pending research has or could include noise and sleep (FAA Noise Impacts Research Workshops, 2009-2010).

With these recommendations in mind, the FAA has launched several research projects through the FAA sponsored and managed by the National Academies Airport Cooperative Research Program (ACRP), the FAA Center of Excellence Partnership for Air Transportation Noise & Emission Reduction (PARTNER) sponsored by the FAA, NASA Transport Canada, DoD and Environmental Protection Agency, and the John A. Volpe National Transportation Systems Center. Below is brief description of several projects.

*Schultz Curve Update:* The dose-response curve initially developed by Schultz in 1978 (Schultz 1978) and endorsed by FICON in 1992 (FICON 1992) is currently used by the FAA. The International Standards Organization (ISO) Working Group 45 is developing a new annex to ISO Standard 1996- Part 1, which specifies methods to assess environmental noise and gives guidance on predicting the potential annoyance response of a community to long-term exposure from various types of environmental noises. The Working Group is considering adopting an updated community annoyance prediction curve based on two data analyses that include more data and more current data. One analysis was conducted by American acoustician Sanford Fidell (Fidell et al. 2011), and another by Dutch noise experts Henk Miedema and Henk Vos of TNO (Miedema & Vos 1998, 1999). The latter approach serves as a basis for the European Commission Position Paper on dose-response relationships between transportation noise and annoyance (EU/ WG2, 2002), which presents curves for noise annoyance from aircraft, road traffic and railway noise. Two dose-response curves derived by teams are essentially identical below DNL 65 dB. Both teams' recent analyses were partially sponsored by the FAA (Fidell et al. 2011; Janssen & Vos 2011; Janssen et al. 2011).

*Alternate and Supplemental Metrics:* Last year the FAA contracted with two expert teams to determine whether the rationale for the primary reliance on DNL to define noise impact remains valid or requires updating to better reflect current understandings of community annoyance caused by aircraft noise exposure. Reports concluded that DNL values for noise exposure of aircraft operations correlate well with other conventional noise metrics. The teams pointed out that there is no improvement in the accuracy of prediction that may be expected from the substitution of other cumulative noise metrics for DNL. Several improvements can be considered, such as modifying the level, time of day, and weighting factors; accounting for the influence of non-acoustic factors; and also using supplemental metrics that are better understood by the public. It was also concluded that in order to modify or replace DNL, a significant new study is required. Fifteen high interest existing aircraft noise surveys were identified as candidates for further analysis, and recommendations for new surveys were formulated.

*Survey Design Project:* The objective of this ACRP project, "*Understanding Public Perception of Aircraft Noise and Noise-induced Sleep Disturbance*," is to develop and validate research protocol for a large-scale study of aircraft noise exposure- annoyance response relationships across the U.S. and to prepare a scope of work for initiating a large–scale study to assess the relationship between aircraft noise and sleep disturbance for U.S. airports. The purpose of the annoyance study would be to determine the extent to which the aircraft noise exposure-response relationship should be updated based on current U.S. data, in view of changes including increases in traffic volume, decreases in aircraft source noise, and public environmental expectations.

*Annoyance and Sleep Disturbance*: Studies on annoyance and sleep disturbance are being carried out under the PARTNER program. Part of the research is focused on assessing how different attributes of aircraft noise (loudness, spectral balance, roughness, tonality, and fluctuation strength) can affect annoyance. Another aspect of the research is focused on understanding the impact of low frequency noise on annoyance. A different project is investigating the impact of aircraft noise on sleep and will attempt to develop models to predict sleep disruption for a given aircraft noise profile.

*Children's Learning:* The FAA supports the mitigation of noise impacts on schools by providing technical guidance and funding for sound insulation. Current criteria for noise impacts on schools and for sound insulation are the same as for residential housing. Should they be the same? An ACRP project *"Assessing Aircraft Noise Conditions Affecting Student Learning"* is aiming to identify and evaluate conditions under which aircraft noise affects student learning and to identify and evaluate alternative noise metrics that best define those conditions.

*Noise Issues beyond DNL 65 dB:* Land areas immediately beyond the DNL 65 dB around airports are experiencing population growth. A Volpe Center project, "*Address Noise Issues beyond 65 DNL Contour Requirements,*" is evaluating measures to address noise outside of DNL 65 dB contours, including the cost/benefit tradeoff of each measure. The concept is to recommend measures that could establish "buffer zones" (Albee, 2003) around airports where noise levels are not deemed to be significant, but may still cause community concerns and engender opposition to airport growth.

## Aircraft noise modeling

The FAA's Integrated Noise Model (INM) is a computer model that evaluates aircraft noise impacts in the vicinity of airports. Originally released in 1978, it is the most widely distributed aircraft noise prediction tool in the world—with over 800 users in more than 40 countries (Fleming 2005). INM has been continually updated since its inception.

Under the auspices of the Next Generation Air Transportation System (NextGen), the U.S. has adopted a five-pillar strategy to effectively address aviation environmental impacts. One of the pillars, to advance scientific understanding and improve integrated noise, emissions and fuel efficiency analyses capability, is being addressed through the FAA's Aviation Environmental Tools Suite initiatives.

*Aviation Environmental Design Tool (AEDT):* AEDT is a part of the Tools Suite. This PARTNER project is focusing on development a comprehensive suite of software tools to facilitate more comprehensive consideration of aviation's environmental effects. It is a software system that dynamically models aircraft performance in space and time to produce fuel burn, emissions and noise. Full flight gate-to-gate analyses are possible for study sizes ranging from a single flight at an airport to scenarios at the regional, national, and global levels. AEDT is currently used by the U.S. government to consider interdependencies among aircraft-related fuel burn, noise and emissions. AEDT is being developed for public release, and will become the next generation aviation environmental tool. In 2012, AEDT version 2a will be released, replacing the current public-use Noise Integrated Routing System (NIRS) for regional noise analysis. That will be followed by AEDT version 2b that will have the airport analysis capabilities that will replace the INM and the Emissions and Dispersion Modeling System (EDMS).

Current FAA noise modeling research is addressing de-rated thrust take-off, behind start of takeoff roll noise directivity adjustment, helicopter spectral data below 50 Hz, expansion of the aircraft database, and improvements in audibility.

*Source Emission and Propagation:* This PARTNER project is focusing on advanced noise propagation algorithms. It models a thrust reverser low frequency noise for aircraft landing operations, effects of complex terrain and meteorology, and high altitude enroute noise.

*Airport Taxiway Noise:* Predicting noise from taxiway operations is minimally addressed in current noise models. The objective of the *ACRP project "Aircraft Taxi Noise Database for Airport Modeling"* is to develop a Noise-Power-Distance (NPD) and spectral class database for nominal taxi, break-away and idle thrust levels to improve taxi noise calculations. The research is mature and is planned to be implemented within the AEDT 2b release.

As aircraft technology continues to advance, modeling tools must continue to evolve to be able to assess new technology. Research exploring the effects of open rotor and supersonic aircraft has begun.

*Multimodal Noise Modeling:* Another future direction of modeling is modeling across various transportation modes (multimodal). At the end of 2010, the ACRP project *"A Comprehensive Development Plan for a Multimodal Noise and Emission Model"* (MDP) was completed (Connor 2011). MDP focused on feasibility and the creation of the process of tool development for a multimodal tool to perform an environmental analysis consisting of noise, air quality, climate and economics for all modes of transport.

## Costs of aircraft noise on society

At the seventh meeting of the International Civil Aviation Organization's (ICAO) Committee on Aviation Environmental Protection (CAEP), held February 5-16, 2007 (ICAO 2007), "the meeting acknowledged the growing complexity associated with assessing noise and emissions effects of aviation, especially when considering impacts and their influence on benefits-costs." The meeting also noted that "to fully assess interdependencies and analyses of the human health and welfare impacts…, it would need to employ tools that were capable of looking not only at one aviation environmental parameter in isolation, but also at the effect that changing one aviation-related environmental parameter has on other aviation environmental parameters." It "would (also) need to frame the impacts of these parameters on common terms, so that it can understand the implications of the interdependencies and make policy decisions taking those implications into account."

The components of the FAA's Aviation Environmental Tools Suite directly relevant to impacts analyses include the following.

*Aviation environmental Portfolio Management Tool for Impacts* (APMT-Impacts): estimates the environmental impacts of aircraft operations through changes in health and welfare endpoints for climate, air quality and noise;

*Aviation environmental Portfolio Management Tool for Economics* (APMT-Economics): models airline and aviation market responses to environmental policy options; and

*Cost Benefit with the Aviation environmental Portfolio Management Tool* (APMT-Cost Benefit): combines Tools Suite output to perform cost benefit analyses.

The APMT-Impacts tool is sub-divided into three modules: Noise, Air Quality and Climate. The methodologies for each module begin with noise and emissions data from AEDT, followed by the calculation of physical and monetary impacts. Impacts and associated uncertainties are simulated based on a probabilistic approach using

Monte Carlo methods. The policy analysis function considers the calculation of the environmental and economic impacts of a policy option relative to a baseline case, where the baseline represents the extrapolation of the status quo. Table 1 below (He 2010) lists the effects modeled under each impact area and corresponding metrics. Additional information is available on-line at http://www.apmt.aero.

**Table 1:** Overview of Environmental impacts modeled in APMT

| **Impact Type** | **Effects Modeled** | **Primary Physical Metrics** | **Primary Monetary Metrics** |
|---|---|---|---|
| Noise | • Property value depreciation (owner occupied and rental properties) | • Population exposed to noise<br>• Noise exposure area | • Capitalized impacts<br>• Annual impacts<br>• Net present value |
| Climate | • $CO_2$<br>• Non-$CO_2$, NOx-$O_3$, cirrus, sulfates, soot, $H_2O$, contrails, NOx-$CH_4$, NOx-$O_3$ long | • Globally-averaged surface temperature change | • Annual impacts<br>• Net present value |
| Air Quality | • Primary particulate matter (PM)<br>• Secondary PM by NOx and SOx | • Incidences of mortality and morbidity | • Annual impacts<br>• Net present value |

As shown in the Table 1, noise costs are estimated using a hedonic property value or hedonic price methods. The property value depreciation metric is the only currently available metric for this type of analysis. Additional data is needed to be able to monetize potential health and welfare impacts of aircraft noise in APMT.

### Noise in national parks and wilderness

The FAA's guidance for assessing aircraft noise for purposes of compliance with the National Environmental Policy Act (*FAA Order 1050.1E, "Policies and Procedures for Considering Environmental Impacts"*) states that special consideration needs to be given to the evaluation of noise impacts on noise sensitive areas within national parks and similar areas where other noise is very low and a quiet setting is a generally recognized purpose and attribute. The DNL 65 dB threshold for significant impact does not adequately address the effects of noise on such areas. Since the early 1990s, the FAA and the National Park Service have collaborated periodically to investigate the relationship between aircraft noise exposure and park visitors' response, but have not yet achieved a generally-accepted systematic approach to metrics or impact criteria.

Currently, the FAA is working in coordination with the National Park Service on AEDT/INM enhancements to improve the prediction of noise for flights over national parks. In addition to modeling enhancements, studies are being carried out on predicting ground based audibility and collecting and analyzing ambient noise data.

*Noise Modeling of Overelapping Flights:* A team at the Volpe Center is working on the development of an algorithm to reduce the over-prediction of the time aircraft noise is audible by accounting for the effect of simultaneously occurring aircraft events.

*Park Visitor Dose–Response*: There is work underway on *Park Visitor Dose-Response* assessment in cooperation with experts on park management, recreational sociology, psychology, and acoustics. This work seeks to establish noise exposure-response relationship for visitors to naturally quiet areas and to develop thresholds for significant noise impact (Anderson et al. 2011).

In addition to visitor dose-response assessment, wildlife dose-response relationships are also of interest Animal response to aircraft noise can range from acute behavior responses to long-term responses. Researchers emphasize the challenges of translating information on wildlife responses to categories of impacts due to the many possible animal responses that may result from a given acoustic exposure. The isolation of aircraft dose from other components of the acoustic environment and correlation with wildlife responses will be difficult and may require manipulation of dose. Researchers have established recommendations for future data collections efforts.

## CONCLUSIONS

The FAA continues to pursue collaborative research activities with other federal agencies, academia, consultants and other parties interested in aviation noise. The studies described in this paper are part of a multi-year planned noise research effort that will be executed as funding becomes available.

The FAA will review research results on a periodic basis. When knowledge is sufficiently mature, research results will inform and guide policy. The FAA is not a solo performer of research. Neither is the FAA a solo decision-maker for potential policy revisions. This will necessarily be a collaborative effort with other agencies engaged in and affected by aircraft noise determinations. There will also be a publicly transparent process for considering new policy directions.

The FAA's future vision is to continue to reduce the impacts of aircraft noise through a balanced approach of aircraft source noise reduction, NextGen operational capabilities, and airport and land use compatibility planning and mitigation. Noise impact and mitigation criteria and land use compatibility guidelines must be based on the best available science. The adverse effects of noise should be addressed where and when it matters, and should be balanced with other environmental considerations. Policy built on a solid scientific foundation should also increase the public trust and understanding in how aircraft noise impacts are described, computed, addressed, and mitigated.

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# Status of international consortium on noise issues in developing and emerging countries

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## ABSTRACT

As part of the growing interest in developing appropriate concepts and approaches for a "Global Noise Policy", consideration needs to be given to how effective and affordable noise policies might need to vary based on factors which differ depending on the "state of development" of individual countries. Although there is no standard manner to distinguish between "developed", "developing" and "emerging" countries, it is obvious that countries do differ in terms of their level of technological development, their financial capabilities and the availability of other resources required for adequate management of community noise. They also differ in their level of knowledge about the effects of noise, their views about the proper role of national and local governments, and the availability of engineering techniques to control exposure to community and occupational noise. Since effective noise policies need to be based on adequate research to understand cultural differences in how people in various countries respond to noise exposures, this topic will be especially important in the future. This paper reviews some of the noise research and noise policy issues which need to be considered as efforts to develop global noise policy concepts proceed and, especially, the ways in which such concepts and exposure criteria might need to be modified to be relevant for "developing" and "emerging" countries. This paper describes the current International Consortium on Noise Issues in Developing and Emerging Countries as a forum to facilitate discussions and share relevant information among the Consortium participants and other interested acoustics professionals.

## INTRODUCTION

Environmental noise continues to pose a significant threat to human health and the quality of life of millions of people throughout developing countries. Urbanization and the associated growth in industrialization and population mobility have resulted in the intensification of environmental noise, particularly in densely populated areas. Many developed, mainly Western, countries and individual cities are now taking actions to enhance their institutional and technical capabilities to monitor and control noise exposure and implement preventive actions to reduce the risks that environmental noise poses to their citizens. This document outlines a Strategic Approach (SA) to Environmental Noise Management (ENM) for developing countries to assist decision makers and stakeholders to formulate and implement effective ENM strategies.

The severity of environmental noise problems in cities of developing countries reflects the level and speed of economic and industrial development. As cities undergo the natural process of development, environmental noise becomes an increasingly severe problem. In the past, the major causes of environmental degradation occurred sequentially rather than simultaneously. However, today many cities of developing countries are suffering pressure from a combination of different driving forces (e.g. motorization, industrialization and increases in urban population density), each with a greater intensity than has occurred elsewhere in the past, but without the well-developed civil infrastructure and financial resources to control them. The result is that the ability of many cities to cope with these combined pressures is often exceeded, leading to a deterioration of environmental quality in many developing countries and increasing negative impacts on their citizenry.

Environmental noise in developing countries has a number of impacts on human health, the quality of life and the environment, which have social and economic implications, as well as problems associated with increasing hearing loss in industrial settings. The effects of noise on humans can include:

- Annoyance
- Sleep disturbance
- Speech interference
- Cardiovascular diseases
- Increases in cardiovascular symptoms (e.g. blood pressure)
- Immune system deficiencies
- Hearing impairment
- Cognitive effects, especially in schoolchildren
- Task and job performance deficits
- Mental health effects.
- In addition, deleterious effects of noise on animals and of vibrations on sensitive, historic building structures can occur.

This paper outlines a Strategic Approach (SA) to Environmental Noise Management (ENM) in developing countries to assist relevant decision makers and stakeholders to formulate and implement effective ENM strategies. The SA aims to mitigate noise by facilitating the setting of noise priorities and by providing direction for institutional development and capacity enhancement. The SA is a natural extension of the recommendations of Agenda 21, derived from the 1992 United Nations Conference on Environment and Development (United Nations 1992), and the Plan of Implementation of the 2002 World Summit on Sustainable Development (WSSD) (United Nations 2002), which requests States to strengthen capacities of developing countries to measure, reduce and assess the impacts of noise, including health impacts, and provide financial and technical support for these activities. In addition, the Strategic Approach supports the UN Habitat Agenda on the Urban Environment and the UNHABITAT/UNEP Sustainable Cities Programme which note the health hazards of exposure to excessive noise, recommend criteria for maximum permitted and safe levels of noise exposure, and promote noise control as part of environmental programs (United Nations 2003; UN Habitat, 2008).

The structure of the SA on environmental noise management was discussed at the Workshop on Environmental Noise Management in Developing Countries at the INTERNOISE 2007 conference, held in Istanbul, 28-31 August 2007 and was then presented at the Noise Policy session at the 2008 Congress of the International Commission on Biological Effects of Noise (ICBEN 2008) (Schwela et al. 2008) and at the INTER-NOISE 2009 Congress (Schwela & Finegold 2009). During the Workshop at the INTER-NOISE 2007 Congress in Istanbul, the following observations were made:

Importance of an overall strategy. Although a step-by-step program of implementation of environmental noise policies is the most realistic way forward, it is also critical that it is done in the context of a clear, strategic approach. Many developed countries lack this long-term vision, as do many developing countries. China appears to be one exception to this as it has developed an impressive strategy to tackle noise. In many ways, this could act as a model for other developing countries.

Importance of implementation and enforcement. According to the 2007 Workshop quite a few developing countries have theoretical noise policies, but the implementation and enforcement of them is poor. This is the result of (a) a lack of political will and (b) of the cost and technical feasibility of adequate noise control. It is probably unrealistic to expect a rapid improvement in implementation and enforcement, so a step-by-step approach would be preferable.

Importance of active citizen groups. There is generally little pressure on governments from citizen groups for action to be taken on environmental noise issues, at least outside of Europe. This is, in part, due to a lack of understanding of the impacts of environmental noise and the associated costs of these impacts. However, citizen groups in China are protesting about aircraft noise and increased noise from traffic on existing roads. When people are annoyed and stressed by noise they don't need to fully understand the impact it is having on them in order to protest. It is likely that these protests will grow as development brings with it an increase in noise.

'New' types of noises will emerge as countries acquire more consumer goods and transportation capabilities, including cars, airplanes and trains. In particular, many of the new consumer goods will result in increases in low-frequency noise. In China, low-frequency noise has become one of the problems which the responsible stakeholders have yet to tackle successfully. Although citizen groups in developed countries have had only had limited success in putting pressure on their governments to tackle environmental noise, it is important that citizen groups from developing countries link up with their counterparts in the developed world.

Importance of improved understanding of the impacts of noise. There is a general lack of understanding in many developing countries amongst both politicians and the general public of the impacts of environmental noise – the effect on stress levels, health, quality of life, etc. It is only when these impacts are better understood that governments will be motivated to tackle environmental noise and citizens will demand exposure to noise to be taken seriously.

Importance of low-cost solutions. At present, tackling environmental noise is not a political priority for most developing countries. It is going to be particularly difficult to persuade them to give some priority to environmental noise and put an effective noise strategy in place if they believe it is going to cost a lot of money. Therefore low-cost solutions are quite important. For example, noise measurement and mapping would be expensive – and probably unnecessary – since most people know where the noisiest areas are. All this means that it is important to highlight the cost-benefit advantages of tackling environmental noise, for example, money spent on noise reduction could result in savings on health costs, but this does require an understanding of the health effects of noise (see previous section).

Importance of not re-inventing research, policy and practice. A considerable body of noise research has been conducted over the past half century and has been summarized by international organizations such as the World Health Organization (WHO). In addition, the noise reduction policies and practices which have been shown to work in developed countries also need to be examined and adopted where relevant. It is important that developing countries linking with international bodies like the International Civil Aviation Organization (ICAO), even though many of these bodies do not yet concentrate on noise research or noise policies which are appropriate for developing nations. Involvement of developing countries will bring a new fresh, perspective to the deliberations of organizations such as ICAO and others. On the other hand, it is also quite important to make sure that both the body of literature on the community responses to noise and national noise policies are appropriate to the circumstances of developing countries.

## ENVIRONMENTAL NOISE MANAGEMENT

### Aim of Environmental Noise Management

The aim of Environmental Noise Management (ENM) is to maintain a low noise "soundscape" which protects human health and wellbeing, but also provides protection of animals and sensitive, historical structures. ENM is a tool which enables government authorities to set objectives to achieve and maintain a low noise soundscape to reduce the impacts of noise. Government authorities in collaboration with other stakeholders can determine the individual steps of the implementation of this process according to:

- local circumstances with respect to background noise levels community values and priorities
- technological feasibilities;
- cultural, social and historical conditions;
- technical expertise about noise control and knowledge about the legal aspects of noise policies, and
- available financial and human resources.

An effective ENM strategy is dependent of a number of factors such as knowledge of noise sources, noise monitoring networks, use of noise prediction models, noise exposure and damage assessments, health based standards together with a range of cost-effective noise exposure control measures, and the legislative powers and resources to implement and enforce them. Figure 1, below, presents a simplified cycle of ENM.

ENM as envisaged in the SA is a process which enables government authorities, in collaboration with other stakeholders, to:

- identify and establish appropriate policies on environmental noise;
- identify relevant legislative and regulatory requirements;
- identify all sources of environmental noise caused by human activities;
- set appropriate objectives and targets for human (and animal) health;
- set priorities for achieving objectives and targets;
- establish a structure and programs to implement policies and achieve objectives and targets;
- facilitate the monitoring of environmental noise and effects on human health;
- facilitate urban planning, corrective action and the prevention of adverse effects;
- ensure compliance with emission and noise standards;

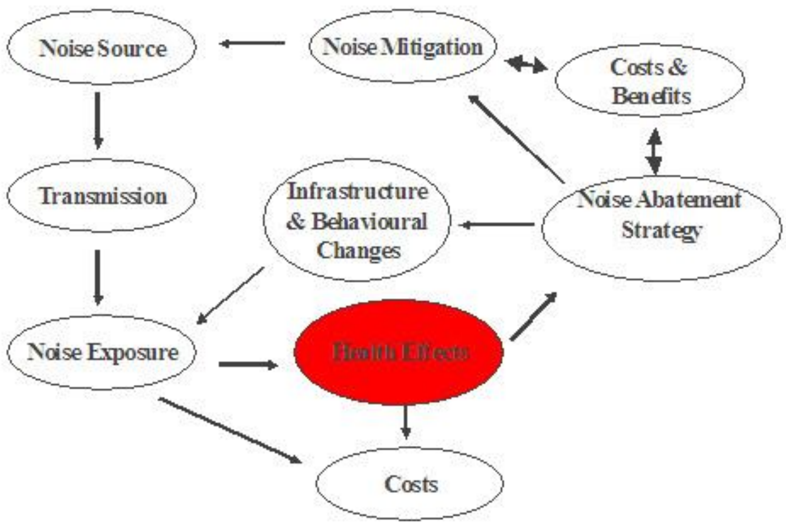


**Figure 1:** Model of policy process for community noise (Hede 1998; WHO 2000)

## Guiding principles of Environmental Noise Management

Guiding principles related to ENM ensure the protection of human health from environmental noise (see Figure 2). However, a number of economic, institutional and political constraints may hamper the full implementation of these principles and, thus, must be addressed. For each component, challenges in developing countries are listed and an objective and tools for improvement of ENM is outlined below.

**Figure 2:** The Guiding principles of ENM

**Access to Environmental Information**: all stakeholders should have access to information regarding Noise
**Awareness**: Provision of information to all stakeholders
**Best practice**: application of state of the technology
**Co-benefits**: consideration of the benefits of integrated ENM, air pollution management including greenhouse gas reduction
**Coherence**: orientation of the efforts of all stakeholders including different neighbouring jurisdictions towards a common objective.
**Concerted effort**: discussion and co-operation among all stakeholders involved
**Compatibility**: development of ENM compatible with regional, national and local needs
**Continual Improvement**: to promote the continual improvement of ENM as well as reduction of noise itself
**Cost-effectiveness**: ENM measured at least cost and highest effectiveness
**Decentralization**: implementation of decentralised ENM with regional, national and local components with due consideration to local capacity
**Equity**: fair and equal protection of all people from noise exposure and consideration of individual vulnerability
**Integrated approach**: development of integrated ENM (prevention, monitoring of adverse impacts, control of sources, and education)
**Opportunity**: sound solutions to noise problems at the suitable moment
**Participation**: active participation of the population in the development and implementation of the plans to minimise noise pollution and prevent the increase of noise levels
**Polluter Pays Principle**: individuals responsible for noise pollution should bare the cost of its consequential impacts
**Precautionary Principle**: where there are threats of serious or irreversible health damage, lack of full scientific certainty should not be used as a reason for postponing cost effective measures to prevent higher noise levels
**Stakeholder**: Commitment of all stakeholders to noise management
**Sustainability**: development of economically and socially compatible ENM which is sustainable over the long term and future generations
**Stepwise approach**: ENM following a target and milestone approach
**Universality**: comprehensive ENM including human health

## Strategic Approach

The Strategic Approach (SA) for Environmental Noise Management in Developing Countries is being proposed by the Stockholm Environment Institute and aims to provide a coherent approach to mitigating noise by facilitating the setting of noise priorities and providing direction on institutional development and capacity enhancement.

The deterioration of noise levels observed in many cities of developing countries is a consequence of industrialization, urban growth, rural poverty and migration of people into urban areas. Environmental noise management aims at maintaining and/or re-installing levels of environmental noise that protect human health. Reduction of excess noise levels is necessary to support further development of developing countries because noise heavily affects public health and the costs on public health associated with noise can be huge. As in air quality management where the benefits of emissions reductions usually are much higher than the costs of source controls in environmental noise abatement the benefits of emissions reductions may also be much higher than the costs of reducing noise emissions. Moreover there may be co-benefits of noise and air pollution (including greenhouse gases) reduction.

The SA is a broad high-level approach that is flexible and adaptable to the needs of different countries and cities. The SA highlights the challenges existing in cities of developing countries and gives recommendations with respect to the most important components of a comprehensive noise management system in a rational and systematic manner. Challenges in environmental noise management in developing countries refer to government commitment and stakeholder participation, to weakness in policies, standards and regulations, to deficiencies in data for emissions, noise and public health impacts. Precise knowledge on noise emissions is often missing, incomplete or inaccurate. Noise emission standards are sometimes obsolete and do not reflect best technical practice. Measures to prevent and reduce noise emissions are often hampered by lack of source apportionment. Low cost and effective alternative technologies are rarely available. Noise monitoring systems are often limited in spatial coverage, not harmonized to each other, or are absent altogether. There is a lack in or absence of quality assurance/quality control plans, the data quality is unknown or poor. Little information exists in many developing countries on health and economic impacts of environmental noise. Risk perception, risk communication, information dissemination and awareness-raising are issues to be addressed. A major challenge is the availability of funding with good governance missing and low priority funding for environmental noise management. Key barriers to the adoption and implementation of the SA include lack of sufficient political will, lack of public awareness, inadequate infrastructure, lack of adequate data for emissions and receiver noise levels and poor surveillance of health impacts due to noise. All these issues have been addressed in the Strategic Approach and tools have been recommended to resolve the challenges and overcome the barriers.

The SA is aimed at all stakeholders who have a role to play in ENM, especially national and local government authorities. Government authorities in collaboration with a range of stakeholders can use the tools outlined in the SA document. The stakeholders also include: judiciary; private sector; civil society, non-government agencies; media, academia and development agencies.

## CONCLUSIONS

This paper provides an overview of a recommended Strategic Approach for Environmental Noise Management in Developing Countries. A draft of the Strategic Approach has been compiled by SEI and future Workshops, Symposia, etc., in collaboration with international experts from developing countries, will be used to refine and evolve the concepts already developed. The SEI report will be used as a background paper for regional policy dialogues and to help cities in developing countries develop action plans for appropriate, effective and affordable noise mitigation. The most immediate step in this process is to develop an international consortium on acoustics experts and other interested persons to share information, plan meetings and Workshops, and promote the SEI concept with the governments of developing countries. The initial emphasis for the beginning of the International Consortium on Noise Issues in Developing and Emerging Countries has been of countries in Asia, although this will be expanded to include countries in South America, Africa and other areas of the world in the near future. Interested persons are encouraged to contact the authors of this paper for inclusion in these activities.

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# The review of market-based measures in mitigating aircraft noise and the applications for Taiwan

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## ABSTRACT

Despite the economic downturns and unexpected drawbacks, the air transport industry is still forecast to experience a 5-6 % annual growth for the next 20 years, with the Asian markets taking the lead. The International Civil Aviation Organization, other international aviation organizations and national governments have stated the importance of applying market-based measures (MBMs) as one of the policy options for achieving the sustainable development of the industry. The MBMs cover environmental charges, taxes, trading and offset, generally applied at the international, national or airport levels, mainly for the purposes of mitigating aircraft noise and/or engine emissions. This paper reviews the current applications of MBMs in mitigating aircraft noise worldwide and investigates the differences and purposes of various measures, with a view for the applications in Taiwan. The current state of noise management measures, covering both regulations and economic instruments, at Taiwanese airports is also described in the paper. Theoretical evaluations of the social costs of aircraft noise have been assessed for comparison against the charge levels of different MBMs where applicable. The outcomes will assist policy makers in applying adequate MBMs for given purposes.

*Keywords: Market-based measures, aircraft noise social costs, charges*

## 1 INTRODUCTION

Sustainable development, which seeks the balance among social, economic and environmental impacts/benefits, has been globally recognized as the main objective of any industry's growth (Caves 1994a, b). The externalities generated from commercial flights have various impacts on air quality, climate change, noise, water quality, fuel consumption and energy, waste and the ecology. Apart from aircraft engine emissions, noise nuisance undoubtedly has the largest social impact on the community surrounding the airport. Noise causes both annoyance (nuisance) and health effects, for instance sleep deprivation (Franssen et al. 2004), stress and hypertension (Issarayangyun et al. 2005; Jarup et al. 2005). The costs of these externalities must be internalized and paid for by the aviation industry and its users (European Commission 1999, 2002).

More and more airports in the world, often through government pressure, have implemented noise-related charges on commercial flights. In 1999, only 14 countries in the world had some form of noise charge; by 2007, 24 countries, 18 European, 4 Asian and 2 North American, have applied such noise-related charges. The schemes for applying these charges vary greatly from country to country, and even between airports in a given country.

In Taiwan, the Civil Aeronautics Administration (CAA), Ministry of Transportation and Communications (MOTC) has been putting lots of effort into mitigating noise pollution in the past years. The current aircraft noise charge has been prevailing for more than 12 years at selected Taiwanese airports now, the CAA recognized that there is a need for revising the noise charge mechanism which aims to find a balance among all parties involved. Section 2 reviews and compares the noise charge schemes at airports worldwide, together with the use of the revenues collected. Section 3 proposed a systematic generic approach to setting up noise charge mechanisms with the consideration of various related factors. Using Taiwanese airports as case studies, Section 4 firstly describes the aircraft noise charge and house insulation schemes in Taiwan, followed by the estimation of noise social costs at 11 Taiwanese airports. Conclusions and recommendations are given in Section 5.

## 2 NOISE CHARGES SCHEMES AT WORLD AIRPORTS

### 2.1 Noise charge principles

Airports in eleven European and four Asian countries, as well as some airports in Canada and the United States, currently apply aircraft noise related surcharges or discounts. The charge mechanisms can be classified into four groups as follows:

- Noise surcharges: for example, Sydney, Vienna, Helsinki, Budapest and Warsaw airports, as well as some airports in Germany, Japan, Italy, Sweden, Switzerland and Taiwan.
- Landing fee based on aircraft noise acoustic levels/categories: for example, Brussels, Tokyo-Narita, Seoul-Gimpo and the UK BAA (British Airports Authority) London airports.
- Noise surcharges and Landing fee based on aircraft noise acoustic categories: for example, ten French airports and Amsterdam Airport Schiphol.
- Other schemes: such as night surcharges at Toronto and Luxembourg airports.

Most airports apply a specific noise surcharge. Some airports apply a percentage surcharge or discount on the Maximum Take-Off Weight (MTOW) based landing fee, depending on the aircraft acoustic category. In the case of BAA London airports, the total landing fee varies according to aircraft acoustic noise category, such that it is impossible to separate out the noise element of the charge. In addition to noise charges/taxes, landing fees at 10 French airports and Amsterdam Airport Schiphol also vary with aircraft acoustic categories.

### 2.2 Use of charges

The purpose of collecting noise surcharges is mainly to mitigate the impact of noise nuisance on the community. Even with the same composition of aircraft movements, the impacts of noise could be reduced by properly investing the money collected into various noise insulation schemes, mitigating measures or even introducing economic incentives for helping airlines in accelerating the use of quieter aircraft.

Table 1 compares the use of revenues from noise charges at various airports. All the selected airports have invested the money on noise related insulation schemes especially on residential houses, schools, hospitals and public buildings. Sydney Airport has invested in building community centers or care centers; whilst Schiphol and Narita airports have used the money in obtaining the land surrounding the airport.

Tokyo Narita Airport had the highest cumulative investment, compared to other airports in Table 1. This was due to the densely populated area and high cost of obtaining the land surrounding the airport. Schiphol and Sydney airports have comparatively high investment in the noise mitigating related measures as well. Taiwan Taoyuan International Airport, being a medium sized airport compared to others, has huge noise impacts on the surrounding area. There was a cumulative amount of US $ 104 million invested in house insulation between year 1985 and 2006.

**Table 1:** The use of noise revenues at selected airports

| Country | Airport | Airport code | House insulation schemes | Region and care centers | Obtaining land | Cumulative investment (million US dollars) | Households within a certain noise contour |
|---|---|---|---|---|---|---|---|
| Australia | Sydney | SYD | ✓ | ✓ | | 346 (up to 2004) | -- |
| Czech Republic | Prague | PRG | ✓ | | | 25 (up to 2006) | 4,288 * |
| France | Charles de Gaulle | CDG | ✓ | | | 67 (up to 2003) | -- |
| Germany | Hamburg | HAM | ✓ | | | 48 (up to 2003) | 14,000 |
| Japan | Narita | NRT | ✓ | | ✓ | 2,682 | 5,489 |
| Netherlands | Schiphol | SPL | ✓ | | ✓ | 835 | 17,000 |
| Taiwan | Taoyuan Int'l | TPE | ✓ | | | 104 (up to 2006) | 25,130 |
| United Kingdom | London-Heathrow | LHR | ✓ | | | 10 (estimated annual spending) | 22,522 ** |

Source: summarized from the Boeing website, www.boeing.com , June 2007; BAA (2007);

Note: * Assuming 2.5 persons per household

** Households within Leq(dBA) noise countour.

## 3 SYSTEMATIC APPROACH TO SETTING UP NOISE CHARGE MECHANISMS

While easing noise nuisance on the local community is a vital task for the majority of the airports in the world, a wider scope of confronting economic, social and environmental issues is necessary and beneficial for the long-term sustainable development of the aviation industry. Section 3.1 presents the generic approach to setting up the noise charge scheme. Two of the important elements of the scheme, namely noise social costs and the use of charges, are further described in Sections 3.2 and 3.3 respectively.

### 3.1 The generic approach

Based on the findings of theoretical research and the review of the current noise charge schemes worldwide, a generic approach to setting up noise charge mechanisms is proposed here, as illustrated in Figure 1. The application of aircraft noise charges involves airports, the surrounding neighborhood, government authorities, airlines and even passengers. The theoretical basis behind noise charges is for internalizing this externality. Hence, the noise social costs should be firstly estimated in order to have a clearer understanding about the true costs of the impacts.

In practical terms, the actual noise charge levels should be then related to the total costs of related noise insulation and mitigating measures. Meanwhile, the charge schemes and levels as well as the equity of the scheme should be accepted by all the actual payers concerned, namely airlines. As the noise charge is part of the airport user charges, the competitiveness of an airport in terms of airport user charge levels should also be investigated while determining the proper charge level for different types/categories of aircraft.

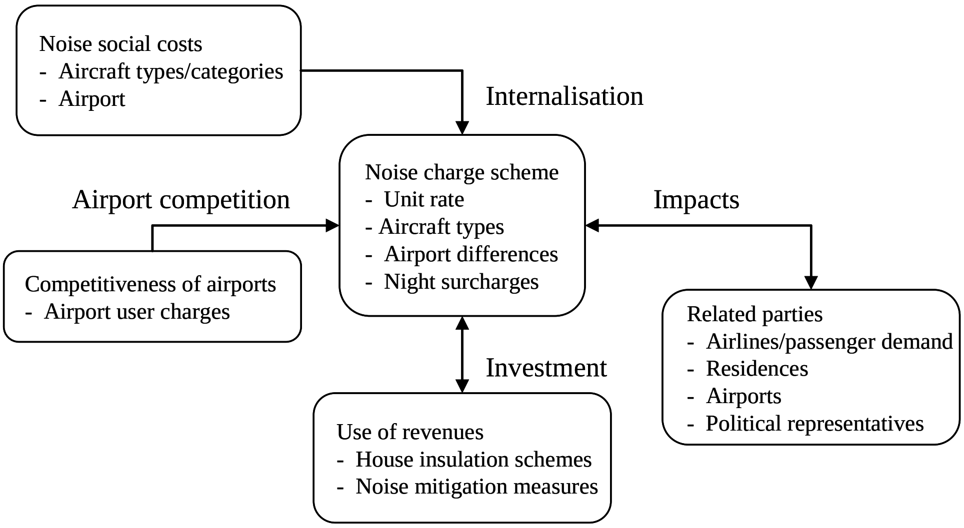


**Figure 1:** The structure of noise charge mechanisms

### 3.2 Noise social costs

The hedonic price method (HPM) is the most commonly used technique for estimating noise damage costs (Lu 2009). This method extracts the implicit prices of certain characteristics that determine property values, such as location, attributes of the neighborhood and environmental quality. By applying the HPM, the annual total noise social cost at an airport could be derived by having the following inputs,

- the noise depreciation index (NDI): the percentage reduction of house price per dBA above background noise. The average NDI from literature review is assumed to be 0.6 %;
- the number of residences within each zone of the noise contour;
- the annual average house rent in the vicinity of the airport: could be derived from the average house value in the area.

After calculating the aggregate noise social cost, it is necessary to decide how to allocate this total external cost to individual flights. The principle of this process should be based on the real impact of noise nuisance generated dynamically from each specific flight. A simplified approach to deriving the marginal noise nuisance (noise index), caused by each specific aircraft/engine combination flight, is developed for the purpose of the research (Lu & Morrell 2006). The calculation of noise index is based on the average of three ICAO (International Civil Aviation Organisation) noise certified levels, namely the Effective Perceived Noise Level (EPNdB) for take-off, sideline and approach, for different aircraft/engine combinations.

With the composition of aircraft movements by aircraft type and engine combinations, the annual noise index could be aggregated. Considering the noise index for different aircraft type and engine combinations, the noise social cost per aircraft movement could then be derived.

### 3.3 Costs of noise mitigation measures

In addition to the charging methods and charge level, a further vital step of establishing an environmental charge mechanism is the use and the implications of revenues, which have been collected from environmental charges.

The ICAO Council identified key policy issues regarding environmental charges and taxes on aviation, and strongly recommended that any environmental levies on air transport should be in the form of charges rather than taxes. In addition, the revenues collected should be applied in the first instance to mitigating the adverse environmental impacts of aircraft emissions.

As this research focuses on the environmental charges imposed by individual airport authorities instead of world-wide or region-wide, the use of charges to supplement government income is eliminated from the analysis. Revenues can be applied in the following ways:

- To compensate for damages from noise nuisance and emissions impacts: the mitigation options include various noise insulation schemes, real monetary compensation for both noise and emissions issues etc.
- To cover the cost of mitigation measures for environmental reasons: such as aircraft noise monitoring system, air quality measuring equipment etc.
- To invest in air traffic control (ATC) improvement: this can reduce the delay of flights due to inefficient ATC systems and heavy traffic demand, and results in the reduction of aircraft engine emissions.
- To invest in more environmentally friendly aircraft and engines: these could be done in two ways: by sponsoring the research of aircraft manufacturers and by creating financial incentives for airlines' purchase of greener aircraft types.

However, the overall use of charges should be based on the cost benefit analysis for each implementation option in order to make the most use of the revenues, which in turn would lead to a better correction of the market failure due to the existing externalities.

## 4 CASE STUDY OF TAIWANESE AIRPORTS

According to "Standards of Charges for the Use of Airport Airfield Navigation Aids and Related Facilities," amended on 29 September 2006, the current noise charge per flight (landing and take-off) can be expressed as the following formula,

$$\text{Noise charge ( NT dollar/flight )} = 17x + 95(y - 73) \quad (1)$$

Where x is Maximum Take-off Weight (MTOW) in thousand kilograms,

y is take-off noise in EPNdB

Currently, the same formula applies to 11 airports in Taiwan that have applied aircraft noise charges. In other words, the same aircraft type flying to Taiwan Taoyuan International Airport, the biggest airport, or to Tainan Airport, a small domestic airport, pays the same noise charge disregarding its actual impacts on residents. Since the same aircraft noise charge has been prevailing for more than 12 years now, the CAA recognized that there is a need for revising the noise charge mechanism so as to take into account: the social costs imposed on residents; the actual expenditure needed for noise insulation schemes; the latest trend of noise charges at world-wide airports; and the competitiveness of Taiwanese international airports. Hence, the revision of noise charge mechanisms is currently a high priority on the agenda of the CAA's work.

### 4.1 Noise control fee for house insulation schemes

The noise charge collected at each of the 11 airports is called “the noise control fee” with the dedicated purpose solely for house insulation schemes. According to the Regulation of Aircraft Noise Control Fee Assignation and Use, the airport must subsidize the sound proofing installation with the following orders of priority (Lin & Liao 2006):

1. The schools, libraries, medical institutions and dwellings in Class 3 aircraft noise control zone, and schools in Class 2 and 1 zones;
2. The libraries and medical institutions in Class 2 zone;
3. The dwellings in Class 1 zone;
4. The libraries, medical institutions and dwellings in Class 1 zone.

Where, aircraft noise control zone classification criteria :

- Class 1 : areas between 60-65 dBA of aircraft noise day-night average sound level ($L_{dn}$);
- Class 2 : areas between 65-75 dBA;
- Class 3 : areas exposed to noise higher than 75 dBA.

Table 2 lists the average annual noise control fees collected at each of the 11 airports, number of households entitled for noise insulation schemes, together with the annual aircraft movements and passengers. (Appendix 1 further lists the households within each noise control zone.) The number of households is clearly not directly related to the traffic volume of the respective airport at all. For Taipei Songshan and Kaohsiung airports, both are very much in the city center, hence, resulting in higher impacts of noise nuisance on the community. Nevertheless, despite less commercial flights, Tainan and Hualian airports have comparatively high noise impacts because of the frequent military aircraft operations. Since the amount collected of the noise control fee is determined from the total commercial flights of an airport concerned, and is not in proportion to the number of households affected, the progress of subsidization at each airport differs greatly.

**Table 2:** The noise control fee and households entitled for noise insulation schemes

| Airport | Commercial aircraft movements 2006 | Passengers 2006 (000) | Annul average noise control fee | | Households |
|---|---|---|---|---|---|
| | | | million NT $ | million € | |
| Taiwan Taoyuan Int’l | 157,703 | 22,857 | 400 | 8.9 | 25,912 |
| Taipei Songshan | 87,955 | 6,729 | 100 | 2.2 | 75,800 |
| Kaohsiung Int’l | 78,603 | 7,130 | 100 | 2.2 | 51,884 |
| Magong* | 34,822 | 1,749 | 23 | 0.5 | 1,409 |
| Kinmen | 22,898 | 1,435 | 15 | 0.3 | 1,265 |
| Taichung* | 18,666 | 693 | 17 | 0.4 | 9,080 |
| Tainan* | 14,114 | 1,231 | 26 | 0.6 | 116,169 |
| Hualian* | 12,888 | 705 | 22 | 0.5 | 68,285 |
| Taitung | 11,129 | 485 | 7.5 | 0.2 | 3,370 |
| Chiayi* | 8,727 | 312 | 15 | 0.3 | 8,443 |
| Pingtung* | 1,560 | 62 | 12 | 0.3 | 2,315 |

Source: CAA (2007b)

Note: * These are military-civil joint use airports. The annual average noise control fee includes the input from the military.

### 4.2 Noise social costs at Taiwanese airports

Applying the hedonic price method described in Section 3.2, this section further estimates the noise social costs at Taiwanese airports. For simplifying the calculation, all the aircraft types operating at these airports are categorized into eight categories, based on their ICAO certified noise levels.

With the data on households within each noise contour zone, annual house rents and the NDI value, the annual noise social costs are estimated for each airport. Comparing with the noise control fee collected at each airport, Table 3 shows that some airports, such as Taipei Songshan, Kaohsiung and Tainan, have higher noise social costs than the actual fee collected. This implies that there could be an increase of noise charges for these airports in order to actually reflect their real social costs. By doing so, the process of insulating houses could be accelerated (instead of taking decades with the current speed of insulation) and resulted in less noise nuisance on the community. On the contrary, the noise control fee collected at some airports (namely Magong, Chiayi and Pingtung) is even higher than their respective noise social cost, implying that there could be a reasonable reduction of noise charges for the flights operating from these airports.

**Table 3:** The annual noise social costs and noise control fees for year 2006

| Airport | Noise social cost (A) in € | Noise control fee (B) in € | (A)/(B) |
|---|---|---|---|
| Taiwan Taoyuan Int'l | 10,074,219 | 8,366,807 | 1.2 |
| Taipei Songshan | 64,845,722 | 1,439,215 | 45.1 |
| Kaohsiung | 17,637,513 | 1,585,262 | 11.1 |
| Tainan | 4,196,948 | 264,300 | 15.9 |
| Hualian | 615,884 | 162,021 | 3.8 |
| Taitung | 825,648 | 124,132 | 6.7 |
| Magong | 154,172 | 355,439 | 0.4 |
| Chiayi | 21,991 | 75,599 | 0.3 |
| Taichung | 378,897 | 121,306 | 3.1 |
| Kinmen | 344,448 | 272,277 | 1.3 |
| Pingtung | 28,505 | 36,364 | 0.8 |
| Total | 99,123,947 | 12,813,621 | 7.5 |

## 5 CONCLUSIONS AND RECOMMENDATIONS

More than 100 airports in the world have applied noise-related charges, either through noise surcharges or landing fees varying with aircraft noise levels/categories. The schemes for applying these charges, a great diversity between airports, have been compared and examined in the paper. With different airport operating characteristics, and historical development of noise related charges and other airport user charges, even different cultures of the country, there is no single scheme which suits all the airports in the world. However, the proposed systematic generic approach to setting up noise charge mechanisms and charge levels could be applied to any airport which wishes to revise their current noise charge schemes or set up a new one. The approach has combined theoretical research results with practical consideration.

With the application of the proposed approach, the results for the revision of noise charges at Taiwanese airports are presented and discussed. The social costs for different airports are served as good reference points for understanding the actual impacts of noise nuisance on the community. With regard to the setting up of noise charge schemes and levels, the practical consideration, such as the costs of house insulation schemes, the administrative procedures and the impacts on airlines, has turned out to be the essential issues, even as constraints, which need to be examined thoroughly. The aim of the revision or setting up of noise charge schemes is to serve the welfare of all parties involved, namely residents, airlines and government authorities etc.

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# Is quiet the new loud? Towards the development of a methodology for estimating the economic value of quiet areas

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## INTRODUCTION

While the adverse impacts of high levels of noise on health, quality of life and well-being are relatively well understood, the beneficial effects of access to quiet are less well recognized and are therefore often overlooked or undervalued in decision-making. The debate on noise impacts stimulated by the emergence of EC noise policy has raised concern about other spaces, particularly those used for recreation, that currently enjoy a peaceful environment, referred to as 'quiet areas'. Some Member States have become concerned that attempts to improve the noise climate in areas of high exposure may lead to a spreading of noise across areas that are currently almost free from environmental noise. This has generated a perceived need for measures or interventions to protect these quiet or tranquil areas.

### Study rationale and approach

The UK Government requires that all new policies, programs and projects are subjected to a comprehensive but proportionate appraisal to ensure that interventions enacted by public sector bodies are in the best interest of society overall. A key component of appraisal is the comparison of the total benefits of a proposal to the full costs incurred by Government and society. While the costs of providing new, or protecting existing ‘quiet areas’ are relatively straightforward to obtain, estimating the benefits is far more difficult, largely because these are not routinely traded in the market place and therefore do not have well established monetary values.

Until the formation of the Interdepartmental Group on Costs and Benefits Noise Sub-Group (IGCB (N)) in 2007, valuation of noise pollution in the UK was centered on amenity impacts[1] through the Department of Transport’s (DfT) webTAG values for annoyance (Department of Transport 2011). The IGCB (N)) was therefore established with a remit to develop and disseminate best practice economic approaches to valuing a wider range of the impacts of changes in environmental noise across all areas of government policy.

In 2010 Defra commissioned a piece of research on behalf of IGCB (N) to promote understanding of the range and value of benefits that people derive from ‘quiet areas’ and to develop an approach that can be systematically and consistently applied by policymakers to assess the benefits that people derive from quiet areas or conversely, the costs of loss of access to these areas. This paper describes some of the key findings from that research.

A comprehensive review of over 80 studies was undertaken to collate evidence on the nature and significance of the benefits that people derive from quiet and relatively quiet areas.

[1] Amenity impacts are defined by the IGCB (N) as the conscious annoyance or negative reaction to noise exposure.

Given the number of potential benefits from 'quiet areas' (including those that are relatively quiet compared to their surroundings), the scope of the review was necessarily broad and looked at (i) areas whose primary purpose is quiet and (ii) how quiet contributes to the overall quality of urban open spaces. This includes:

- areas that are absolutely quiet in terms of dBA levels (i.e. below a certain threshold),
- areas that are relatively quiet i.e. they are significantly less noisy than surrounding areas (an urban park with plenty of trees or other open spaces),
- areas that are quiet but not necessarily considered tranquil (an urban waste land),
- areas that should be quiet but are not (a side street which is used as a rat run),
- areas that are sensitive to noise but may or may not be quiet (churchyards and cemeteries).

DEFINING QUIET AND QUIET AREAS

There is no universally agreed definition of "quiet" or "quiet areas". Approaches taken to identify quiet and quiet areas generally fall into four distinct categories:

- Quantitative methods based on noise levels. These measured and/or predicted noise levels and may relate to absolute or relative quiet, i.e. how quiet an area is relative to its surroundings or an absolute threshold above which an area is deemed not to be quiet. Different values may apply for daytime and night-time periods.
- Quantitative methods based on location, or distance from major noise sources, etc. Such approaches may be appropriate in a rural context, but are unlikely to be applicable to urban quiet areas.
- Subjective methods based on users' identification with, and use of, quiet areas
- Subjective methods based on audibility of acoustic features, natural sounds, etc.

The research relating to the value of quiet is consistent in asserting the complexity of "quiet" and that one's experience of 'quiet environments' is inextricably linked with overall perceptions of the character and quality of the landscape or context in which it is present, on the soundscape (Kull 2006; Nilsson 2007) and, to a certain extent, with prior expectations (Memoli et al. 2008; Bruce et al. 2009). For example, evidence from a survey conducted as part of a previous study on tranquility in Westminster (Scott Wilson Ltd. 2009) revealed that park users in Westminster, London felt a range of factors or 'pillars' of tranquility were as important as relative or absolute quiet and these included the culture of a place, safety record, visual amenity and presence of nature. While the evidence did reveal the importance to residents, visitors and workers of spaces that are 'significantly quieter', noise levels in these spaces were rarely below 55 dB $L_{Aeq}$. The study suggested that areas with average noise levels in excess of 55 dB $L_{Aeq}$ still had the potential to trigger tranquility if the other experiential factors distracted, or masked (i.e. enabled people to switch off) the ambient noise levels.

In light of these findings, a subjective definition of quiet was applied. It is nevertheless recognized that in practice, identifying quiet areas is likely to include at least one objective element. The following key defining points, or tests of quiet, are considered appropriate:

- natural sounds are audible and not masked by man-made sounds – the Sound Quality test; and
- for relative quiet, the whole area or part of the area is noticeably less noisy than its immediate surroundings – the Relatively Quiet test.

For a subjective definition of quiet areas, one further test was developed, the Potential Use test which has two key indicators:

- an area users choose to visit due to its quiet nature (whether absolutely or relatively quiet, or an absence of inappropriate or unnecessary sound, perceived or not – for example escaping the hustle and bustle, whilst not a conscious decision about noise levels, has a very strong association with relative quiet); and
- an area used for quiet activities such as reading, strolling, meditation and reflection[2] .

The outline for an objective definition of quiet areas, based on recommendations from the literature reviewed is included below:

- Maximum noise level of 55 dB $L_{day}$. This level would apply at the perimeters of the space, and ideally levels within the space would be well below this level. Areas that are quiet for parts of the time (when they are likely to be used) should also be considered.
- For relatively quiet areas, the noise level across the majority of the area must be at least 10 dBA below the noise levels of the surrounding areas (e.g. possibly defined as the noise levels associated with all dwellings within a 200 m radius).
- The area that satisfies the noise criteria must meet a minimum area constraint to prevent the inclusion of large numbers of very small areas (e.g. area meeting noise criteria must be at least 1 ha);
- Any public open spaces shortlisted by the relevant Local Authority as candidate quiet areas.

To test this approach, some initial area selection was carried out (together with Westminster City Council) to identify potential quiet areas within the City of Westminster before these were tested against the above criteria. The quiet areas selected included a large public park (St. James's Park), a smaller park bounded by a canal on one side in a residential area (Westbourne Green) and a paved urban space (Golden Square) off a busy road.

Noise monitoring was conducted at each of these sites and used to refine the above objective (absolute and relative) approaches to defining quiet and relatively quiet areas in the context of available noise data and local knowledge and to determine which areas would be subjectively considered as quiet or relatively quiet areas.

[2] Consideration should also be given to the fact that some 'quiet areas' may also be used for criminal activities (e.g. mugging).

## THE BENEFITS OF QUIET AND QUIET AREAS

The literature suggests that quiet (or absence of unnecessary or inappropriate sounds) has a number of important and often co-related benefits to human well-being, including improved creativity, problem solving, mental health, concentration and undisturbed sleep. In addition to the direct economic benefits that human well-being confers (in terms of, for example, savings on health costs and increased worker productivity), access to "quiet areas" also offers other services of economic and social value including impacts on property values (people generally prefer to live in "quiet" neighborhoods) and benefits to the wider community, including children and the elderly. The body of evidence reviewed relating to the benefits of quiet and quiet areas is summarized in Table 1.

**Table 1:** Evidence relating to the benefits of quiet and quiet areas

| Broad Category | Benefits | Evidence |
|---|---|---|
| Health | Mental well-being | Berry & Flindell (2009); Defra (2010); New Economics Foundation (2005); Chu et al. (2004); van Kamp & Davies (2008) |
| | Psychological restoration / recovery | Clark et al. (2006) |
| | Psychological well-being, including stress release / relief | Öhrström et al. (2006); Gidlöff-Gunnarsson & Öhrström (2007) |
| | Physiological well-being (reduced risk of cardiovascular disease and hypertension) | Berry & Flindell (2009); Defra (2010); Health Protection Agency (2010); Babisch (2006); Sørensen et al. (2011) |
| Amenity | Reduced annoyance reflected in property price premiums | Bateman et al. (2001), Navrud (2002); Wardman & Bristow (2008); Nelson (2004) |
| | An escape from the 'hustle and bustle' of surrounding (relatively noisier) areas | van den Berg & van den Berg (2006) |
| | Relaxation / Recreation | Berglund et al. (2004); Gidlöff-Gunnarsson & Öhrström (2007); Klæboe (2005) |
| | Spiritual | Prochnik (2010) |
| | Quality of life | Lawton et al. (1980) |
| Productivity | Creativity and problem-solving | Stansfeld et al. (2000); Clark & Stansfeld (2007) |
| | Aid to concentration | Berglund & Lindvall (1995) |
| | Cognitive development | Berglund & Lindvall (1995); Evans & Maxwell (1997); Berry & Flindell (2009) |
| Ecosystems | Biodiversity (habitats for breeding, foraging, etc) | Environmental Protection UK (2010) |
| | Air quality (induced) | Environmental Protection UK (2010) |

To date, most research effort has been dedicated to understanding the relationship between noise, annoyance and health. There is comparatively little focusing specifically on the benefits of quiet and access to quiet areas. This may be partly as a result of the complexity of defining quiet and quiet areas. Nevertheless, using a combination of evidence from the literature on the influence of noise on people's enjoyment of urban open spaces, it is clear that both 'quiet' and access to 'quiet areas' (or opportunities to experience freedom from unwanted sound) make an important contribution to human health and well-being, with growing interest in the restorative benefits.

In the absence of quantitative evidence on the benefits that people derive specifically from quiet and quiet areas (i.e. over and above those obtained through a reduction in noise levels), the scope of the literature review was broadened to investigate whether or not it is possible to determine the contribution of quiet to the overall quality of urban spaces. Interest in the social, economic and environmental value of urban spaces has grown considerably over the last decade, with both qualitative and quantitative studies on streets, parks and open spaces.

One particular gap in the evidence base is where quiet ranks amongst the many different features of urban open spaces and whether removing quiet (i.e. allowing more noise into such spaces) creates a snowball or tipping effect whereby other key amenities (e.g. biodiversity, mixing of ages groups) also suffer and users start to vote with their feet. The study included some preliminary testing of questions to users of public open spaces that might illuminate this tipping point further. However, there appears to be no existing mechanism or conclusive evidence for estimating the difference between the value of a quiet open space and a similar non-quiet open space. Furthermore, the evidence that does exist appears to focus overwhelmingly on the benefits or attributes that are important to users of open spaces; there is relatively little that examines the features that are important to non-users or those who could use a quiet area or urban open space but choose not to.

## THE ECONOMIC VALUE OF QUIET AND QUIET AREAS

There has been significant progress in the quantification and valuation of environmental noise impacts over the past decade, as well as advances in spatial modeling, allowing estimation of average noise exposure across defined areas. However, until fairly recently, valuation of noise pollution, at least in the UK, has centered on amenity impacts[3] using hedonic pricing analyses (see for example, Tomkins et al. 1998; Bateman et al. 2001, 2004; Day et al. 2007) that examine the impact on property prices of households' exposure to road and rail noise. These studies fail, however, to capture the value of quiet areas to those who (i) may not be able to afford to live in 'quiet' neighborhoods and arguably, for whom, a quiet space in a noisy neighborhood would be more highly valued and/or (ii) those who may work in a noisy environment and seek refuge from the 'hustle and bustle' during the day.

The open space literature provides an indication of the direct and indirect use values of public parks, greenbelt and undeveloped land (McConnell & Walls 2005; CABE 2005; CLG 2006; The Trust for Public Land 2009; Green Space 2010; Gensler & the Urban Land Institute 2011) but no studies specifically identified 'quiet' as a valued benefit. Some studies (e.g. CLG 2006) infer a value for tranquility from existing studies, where tranquility is defined as the effect that undeveloped land may have in buffering nearby residential properties from noise, vibration and light pollution.

[3] Amenity impacts are defined in Defra (2008) as the conscious annoyance or negative reaction to noise exposure.

The studies reviewed demonstrate a number of important points. First, not all forms of open space are valued equally by households. Rather, values are determined on the basis of environmental quality (including security) and the available facilities. In the context of US studies for example, parks designed for natural habitat preservation and light recreation contribute significant amenity effects and outperformed golf courses with respect to neighboring property value enhancement. Second, developable open space such as farmland and forested land (and sometimes vacant sites) provide amenity effects although at lower levels than permanently protected open space. Third, there is a limit to how far the externalities from parks extend. Again, the results from US studies suggest that the externalities do not extend much beyond 450 m suggesting that a larger number of smaller open spaces may be more valuable than a single, large open space.

## CONCEPTUAL APPROACHES TO VALUING QUIET AND QUIET AREAS

Three possible approaches to valuing quiet and quiet areas were considered:

- using values for urban green spaces as a proxy for “quiet areas” to identify an upper range estimate of the value of quiet areas. Drawing on recent initiatives (e.g. by CABE 2005; CLG 2006, etc.) and valuation studies on green open space to estimate, through the process of benefits transfer, the economic value of urban open spaces, studies to assess the impacts or opportunity costs of proposed (or actual) developments on greenfield sites and how these may impact on ‘quiet’ and/or the types of activities (e.g. recreation, reading, meditation, etc) that take place in these spaces;
- estimating the opportunity costs of maintaining undeveloped sites; and
- making use of existing values for noise disturbance in the home (i.e. based on the webTAG values). This would, however, only be applicable to a change in the level of noise/quiet and would not therefore reflect the value of those ‘quiet spaces’ that are actively sought. While such an approach could at least provide a starting point, it is important to note that it would be open to criticism.

The first approach is conceptually preferred as it is based on values for spaces that exhibit quiet characteristics. Once the method is established it may be refined as evidence on the relative contribution of quiet and other attributes to the overall value becomes available. In the absence of such evidence any results derived are necessarily heavily caveated and may well over-value quiet.

## CASE STUDY

Using information from noise mapping, the literature review and primary research, the benefits transfer approach was applied to estimate an economic value for Westbourne Green, an open space in west London that exhibits clearly discernible changes in noise level from the centre of the open space to the surrounding area.

It is estimated (on the basis of a short observational survey) that around 2,000 people visit Westbourne Green each day. This includes both those for whom the Green is a destination in itself and those who use it as a thoroughfare. In addition to the users, there are also a number of non-users who may nevertheless value the space. These include people who live in the vicinity of the space and may therefore benefit from increased property values as a result of having a nice outlook or a quieter environment, as well as people who simply value the existence of the open space. The case study is limited to use values only.

Under a baseline scenario, and using adjusted monetary estimates from studies on the value of public parks in Australia and the US (Lockwood & Tracy 1995; The Trust for Public Land 2001), the use value of Westbourne Green is estimated to lie between £1.18 and £7.40 per visit, or between £861,400 and £5,402,000 per year. This could reasonably be considered as an upper bound for the use value of the park.

A hypothetical change scenario is then introduced to examine the impact of the development of a new road scheme to the south of the Green which will result in a substantial increase in traffic flows along a major traffic artery (the A40) and an associated increase in noise levels within Westbourne Green.

A field survey of visitors to Westbourne Green indicated that one third of users would move away if subjected to continual loud traffic noise. Assuming a complete loss of utility to these users, the resulting welfare loss is estimated to lie between £284,130 and £1,782,660 per year. This estimate does not, however, account for those users who simply relocate to alternative quiet spaces nearby (with little or no change in utility) and those who continue to use Westbourne Green (perhaps because there are no convenient alternatives or choose instead to spent time in quieter parts of the space) but whose use values have been reduced as a result of the increase in noise.

The case study is a necessarily crude illustration of one approach to valuing quiet using available information on the value of urban open spaces. It ignores non-use values and does not account for those users who may continue to use the space but whose WTP to use the space is diminished by the increase in traffic noise, or those who are able to make use of alternative open spaces.

Using a similar approach, it is possible to derive an aggregate estimate for the value of quiet in England as a whole. An ICM poll conducted in 2009 found that 31 % of the population regularly visits quiet areas. Without a definition of ‘regular’ two scenarios are assessed: the first assumes one visit per person per year giving a total of 16.12 million visits per year nationally. The second assumes one visit per person per month giving up to 193.44 million visits per year. There is, however, a high degree of uncertainty around the number of visits specifically motivated by a desire for quiet, not excluding of course those trips made for other reasons but where quiet is a critical component of the package of experiences. Once again employing the use values of £1.18 to £7.40 per visit (which are themselves highly caveated and reflect the use value of green space in its entirety), the total use value for visits to quiet areas for England as a whole is estimated to lie somewhere between £19.02 million and £1.4 billion per year.

This estimate covers a wide range and includes only those who visit open spaces expressly for the purpose of experiencing quiet. These estimates do not include the value held by those users who visit open spaces for other reasons but gain added utility from the quiet and the non-use values held by those who may not necessarily visit quiet areas but derive benefit from knowing that quiet areas exist and/or from a premium on the value of properties located in or near to quiet areas.

## CONCLUSIONS

As is evident from the review findings, very little research has sought to evaluate the benefits of quiet, taking ‘quiet’ or ‘relative quiet’ as the starting point. Rather, studies have typically focused on the effects of noise or the impacts of changes in environmental noise levels above a 50 dBA threshold.

More broadly, it is clear from both the review and study findings that much more effort is needed to ensure that acoustic factors (including noise, soundscape, quiet and tranquility issues) are included on the agenda when considering open space. While 'quiet' does not explicitly feature as one of the most highly ranked attributes of urban open spaces amongst users, it is an implicit feature of other benefits that are considered very important including 'an escape from hustle/bustle' and a place for 'rest and relaxation'. This suggests too that quiet areas are valuable and need to be protected and enhanced. There is a clear need for empirical research to establish the specific value of "quiet" in open areas.

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# Noise research & policy in the USA: emerging from the shadows

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## ABSTRACT

For political reasons, noise policy in the USA has been at a standstill for three decades. But changes began ten years ago in the health care sector and gathered force over the past three years. These changes now appear poised to yield significant results. What enabled change is a non-confrontational approach to noise policy that focuses on incremental improvements in specific sectors such as: health care, education and sustainable office buildings. In these sectors, a particular noise consideration, speech privacy, is as important a consideration as noise. However, privacy is governed by laws that don't concern traditional foes of noise policy. The new approach taken by our committee focuses on setting achievable goals with respect to privacy and noise immission (i.e., reception or injection of materials such as pollutants; in other words the impacts of noise and privacy on the performance of the indoor occupants of buildings) instead of confronting political foes who are opposed to regulating outdoor noise by reengineering the sources of noise. In other words, focusing on noise immission into--and privacy within--hospitals and schools avoids confrontation with the economically powerful opponents of noise policy in the transportation, energy and manufacturing industries who have traditionally blocked attempts to regulate noise emissions (i.e., regulating noise at its source). This sector-specific, immission-oriented approach enabled the continuation of scientific research on the impacts of noise on health, educational outcomes, and workplace performance. With the recent publication of the report, *Technology for a Quieter America* by the U.S. National Academy of Engineering, noise policy appears ready to take the next step forward.

## INTRODUCTION

Permit us, with due humility, to start with a conclusion and then fill in the rest. The table below is where we (our committee) in the USA are as of January 2010 when this table was published. Later on in this article, because change—as scientists say—is a constant, we will describe the slightly different place we plan to be by January 2014. The table below is an excerpt from the 81-page "Sound & Vibration Design Guidelines for Health Care Facilities Version 2.0, January 2010." This document is cited in building codes in the United States and sixteen other countries and is the Reference Standard for two rating groups: the Green Guide for Healthcare (2007), and the U.S. Green Building Council's LEED Green Building Rating System (2011), the standard for sustainability buildings in the USA. As such, this table has become the basis of current policy on speech privacy in several countries. However, it is neither fixed nor permanent—that is, it continues to evolve for reasons we will explain.

NOTE: This table has two headings that refer to the two original publications in which it is cited, both of which were published in January 2010. Subsequently, several other policy documents have also cited this table, including the Green Guide for Health

Care and the US Green Building Council's LEED for Health Care, but these publications do so by referring to one or both of the following original publications:

First headline below: The 2010 FGI Guidelines for Design and Construction of Health Care Facilities, published by the Facility Guidelines Institute and distributed by the American Hospital Association and the American Institute of Architects;

Second headline below: Sound & Vibration Design Guidelines for Health Care Facilities, Version 2.0, January 2, 2010. This document is the sole reference document for all acoustical criteria included in the 2010 FGI Guidelines (above).

**2010 Guidelines Table 1.2-4: Design Criteria for Speech Privacy for Enclosed Room and Open-Plan Spaces**

Table 4.4-1: Speech privacy goals for enclosed rooms

| Enclosed Rooms Goal | AI | PI | STI | SII |
|---|---|---|---|---|
| Normal | ≤0.15 | ≥85% | ≤0.19 | ≤0.20 |
| Confidential | ≤0.05 | ≥95% | ≤0.12 | ≤0.10 |
| Secure | Special consideration required. | | | |

Table 4.4-2: Speech privacy goals for open-plan spaces

| Open Plan Goal | AI | PI | STI | SII |
|---|---|---|---|---|
| Normal (non-intrusive) | ≤0.20 | ≥80% | ≤0.23 | ≤0.25 |
| Confidential | Special consideration required. | | | |

## Brief history

This short chart has a sixty-year-long story. Briefly: the story began in 1948 in Cambridge MA USA with the founding of Bolt Beranek and Newman, a company that began in the research laboratories of the Massachusetts Institute of Technology. One of the founders of the company, Leo B. Beranek, while consulting at Bell Laboratories in New Jersey, worked on an important concept having to do with "noise" and how it interfered with airplane pilot communications. To calibrate the levels of noise, the group developed an index of "intelligibility," referring to the intelligibility of speech against a background of interfering noise.

Dr. Beranek brought this concept with him to his company, Bolt Beranek and Newman. In 1953, his colleague William Cavanaugh (another graduate of MIT and the co-author of this paper) was confronted with a client problem involving lack of privacy in offices encountered by The Owens Corning Corporation. Cavanaugh's team was asked what to do about it. So Cavanaugh talked to Dr. Beranek. They drew a horizontal line with "intelligible speech" on one end and "un-intelligible speech" on the other end. And they realized that the difference between "intelligibility" and "un-intelligibility" corresponded to the level of background noise. That is: background noise, by creating "unintelligibility," thereby creates speech privacy.

By 1954, this work had been published in a paper by Cavanaugh's team in the Journal of the Acoustical Society of America. And then in 1969, it was the basis of a standard issued by the American National Standards Institute, ANSI standard S3.5.

That standard became the basis of another standard in the 1970's from the American Society of Testing and Materials, ASTM E1130. Both standards were updated several times, but preserved the use of "unintelligibility" as the basis of speech privacy. Thence followed separate standards from ISO and other groups—all adhering to the concept of intelligibility, but applying different metrics. And then in 2001—during a period of intense interest in privacy and security, it crossed back over into telecommunications in another ANSI standard maintained by the U.S. Department of Commerce Telecommunications and Information Agency (TIA), ANSI standard T.1-523-2001/Glossary. This standard, respecting scientists' interest in parsimony, states this elegant eight-word definition which applies to all of the various standards developed over six decades and therefore, perfectly suited for adjudication in law courts: Speech privacy: "….techniques to render speech unintelligible to casual listeners."

This sixty-year-history has been our committee's ally, providing a body of effort and cumulative evidence that enabled us to overcome the "punctuations" and historical discontinuities that took place during the period in which we were actively developing public policy.

### Standards are not public policy

Writing a standard is one thing. Making effective public policy is something else. And "globalizing" that policy across cultures is something else altogether. Clearly, there are vast differences in policy-making between countries in North America, Europe and Asia. And the challenge facing the authors' committee, ANSI S12 WG44 (a corresponding committee of the International Standards Organization), was this: How to develop effective, science-based policy for regulating speech privacy that could be applicable to all of the nations of the world, despite their cultural differences in making and enforcing policy?

### One way to look at it: punctuated equilibrium

Harvard University's neo-Darwinian biologist, Stephen J. Gould coined the term "punctuated equilibrium" in the 1980's, turning the field of evolutionary biology on its head. What he noted was that evolution is not continuous. It actually starts, stops, accelerates for short periods, drifts for extended periods, stops, starts again. And, he noted, these "punctuations" seemed to correspond to major events that affected the Earth's climate, such as the collision of massive asteroids into the Earth's surface, causing mass extinctions. In other words, evolution is not a gradual, continuous and uninterrupted striving toward perfection, but rather a series of imperfect adaptations to current conditions.

These concepts of "equilibrium" and "punctuated equilibrium" from evolutionary biology are useful for looking at the processes of policy-making in different parts of the world. For example, to return to the discussion of privacy, the development of policies with respect to privacy and security are frequently "punctuated" by global events. In 1948, the United Nations approved the "Universal Declaration of Human Rights" enshrining the concept of privacy as a fundamental human right. And that concept of privacy as a fundamental right was subsequently written into the constitutions of many countries, particularly in Europe.

Not so in the United States, which already had an 18$^{th}$ Century "Constitution" and a "Bill of Rights" neither of which explicitly say anything about privacy. Thus, as a nation of immigrants with no common culture bound together by an economic philosophy based on property rights, privacy in the United States became defined not as a natural right, but rather as a "property right." That is, U.S. citizens are deemed to "own" certain information about themselves that is their "property." But they have no fundamental, natural right to privacy.

Then in 1995, the European Parliament passed the privacy protection statute 9546EC, inducing most nations to respond by developing their own "universal" privacy protection laws to mirror the European law and citing the U.N.'s "Universal Declaration of Human Rights" as the source. But the United States pursued its own path. Unable to develop a single federal law to protect the privacy of its citizens, the United States Congress passed two separate, limited laws aimed at protecting certain aspects of citizens' private property: one covering the healthcare industry and protecting citizens' healthcare information and the other covering the financial services industry, protecting their financial information. And then, to confuse matters further, these two laws were handed to two different agencies of the federal government both of which were separately tasked with developing their own regulatory enforcement mechanisms.

Not so in neighboring Canada. There, mirroring the European model, Parliament passed a single, elegant privacy law and established a Commissioner of Privacy for the entire nation. And the national law was mirrored in additional laws in each of Canada's sixteen provinces, each managed by a provincial commissioner of privacy.

But in the United States, a major punctuation had occurred a few years earlier in the form of a political change called the "Reagan Revolution." This resulted in a thirty-year period of "de-regulation" during which the role of the federal government was consistently reduced. And among the issues that were swept off the table during this period of de-regulation was anything having to do with regulating acoustical matters, such as noise and speech privacy.

To add to this, privacy protections traditionally suffer during war time—as nations become obsessed with security. And this was certainly a major concern around the world during the first decade of the second millennium. For Americans, the date 9.11.01 has become a terrifying totem of an era of global terrorism that caused government to sweep aside all concern about citizens' privacy in the interests of protecting state security. So in the U.S., despite having passed two national privacy protection laws, all efforts to enforce them were eclipsed by the war on terror. This set severe limits on the work of ANSI S12 WG44.

**Fragmentation and discontinuity as opportunities: Nine rules for developing science-based public policies for noise control in the USA after 1981**

This three-decade period of anti-federalist fragmentation, de-regulation and obsession with security persisted in the United States until 2009, by which time our committee's work was nearly done. During this period, fragmentation raised significant hurdles to the effort to build a simple, coherent, science-based, national framework for regulating speech privacy. In fact, to deal with this fragmentation, it was essential for ANSI S12 WG44 to adopt nine rules of behavior that are reflected in the table at the beginning of this article. And while none of these rules is revolutionary—indeed, the authors believe practices such as these would be regarded as common sense in most cultures—we humbly hope they will prove to be useful to others around the world who are seeking to develop effective public policies for noise control in political challenging environments.

**Rule 1:** Neutrality – It was essential to focus on global need and resist efforts to politicize or regionalize the work we set out to do.

**Rule 2:** Stick to science – It was equally essential to work within the body of established science and standards in the field of speech privacy and to avoid re-writing that science or attempting to refine or change the scientific methods and standards involved.

**Rule 3:** Be representative – While many standard-setting groups attempt to limit the number of participants and control the dialogue, it was essential for our work to reach out to hundreds of people representing nine constituencies, including many outside the acoustics profession, and to expand the group until it ultimately numbers over 520 members and over 45,000 auditors.

**Rule 4:** Form partnerships and alliances – Working in a vacuum is dangerous, so it is essential, before you begin work, to clearly identify the goals you want to achieve, and then form partnerships and alliances with groups that will use the end product of your work. These groups need to be engaged in the development process from the beginning.

**Rule 5:** Focus on parsimony – Throughout the period of fragmentation, specialist groups around the world had evolved several different methods to which they were committed (AI, PI, STI, SII)—all based on the same core concept of "intelligibility/unintelligibility" for measuring speech privacy. It was therefore necessary to reconcile the differences between these methods and thereby cut through the Gordian knot. Selecting just one and rejecting the others would have been disastrous.

**Rule 6:** Forge Consensus – Issues concerning privacy and acoustics—at least in the United States—lack the support of large constituencies. For this reason it is essential to build bridges to outsiders whose beliefs and interests align with committee work. The support of these outsiders becomes an essential ingredient in making a case to government that your concerns are significant and supported broadly.

**Rule 7:** Set limits – There is constant pressure to "reinvent the wheel" or to design perfectly engineered solutions. However making effective policy requires working with the tools you have available and staying within the bounds of existing science and technology.

**Rule 8:** Catch the wave – It is essential to move quickly to meet a social need as it arises.

**Rule 9:** Lead – Large groups require strong leadership. Lead by example not by force.

### In 2008 a new opportunity for speech privacy arose from the struggle over climate change

A tectonic shift took place in the United States with the election of 2006 that enabled Congress for the first time to begin dealing with the climate change issue after 30 years of resistance. This created an opportunity to place speech privacy on the agenda along with other acoustical issues as part of a broad, emerging concern known as "Environmental Quality."

**2011 to 2014: Four next steps**

One consequence of the "punctuated equilibrium" approach to developing pubic policy is that perfection is never attainable because underlying conditions are always changing—sometimes abruptly—necessitating new adaptations. So where we stand with regard to speech privacy policy in 2011 is already changing. Following are the adaptations that ANSI S12

WG44 will need to make as part of the revised "Sound & Vibration 3.0" that will be published in January 2014. We have already been at work on all of these changes since 2008—two years before the 2010 edition was published.

A. Accommodating a new standard developed in Canada. A group at the National Research Council of Canada led by John Bradley PhD and Bradley Gover PhD began working on a method for measuring "speech security" which they conceive as a more secure level of speech privacy. "Speech security" extends the concept of "rendering speech un-intelligible to casual listeners" to include rending speech completely indiscernible by anyone, not just casual listeners. It does not, however, deal with the problem of "bugging" or "assistive listening devices". This Canadian work was released in December 2008 as a new standard, ASTM E2638. However, this was too late to include the new work in the 2010 documents for which the public review periods had already closed. So, meeting first in Paris, France in July 2008, ANSI S12 WG44 began working on a method to include the new standard in the speech privacy framework published in 2010. Thus, the 2014 edition of "Sound & Vibration 3.0" will include a fifth measurement method as established in ASTM E2638.

B. Answering concerns about infection control. In the United States, noise and privacy problems in healthcare facilities confront strong resistance from healthcare professionals whose penultimate concern is controlling the spread of infections, known as "nosocomial" or hospital-acquired infections such as MRSA. Controlling noise requires adding absorptive materials to surfaces such as ceilings, walls and floors. And in healthcare facilities, medical professionals are concerned that absorptive materials may harbor the growth of bacteria and viruses. It is therefore essential for ANSI S12 WG44 to undertake a two-part program: (1) educating the acoustics industry about the need for new absorptive materials that are cleanable and that do not harbor the growth of harmful organisms; and (2) educating healthcare professionals that new materials are available to meet this need.

C. Accommodating concerns about "green materials." The rapid drive to "green" the built environment (around the world, this effort has been underway for many years, but in the United States it re-started abruptly in 2007 when the "Reagan Revolution" finally collapsed) has created great pressure on the acoustical products industry to develop new "green" products. In fact, entire new classes of products are emerging such as "thermo-acoustic insulation" based on nanotechnologies. ANSI S12 WG44 has sought to focus attention on these emerging needs and new products through a series of public symposia on "Acoustics in Green Buildings" that have been held in the United States since 2008.

D. Ensuring that solutions meet budgetary constraints resulting from the global financial meltdown that caused a worldwide recession beginning in 2007. Even major industries like health care and financial services are under severe budgetary pressure. So solving acoustical problems like speech privacy must be done within these constraints. In the United States, regulatory compliance with privacy laws is subject to a rule about "reasonable safeguards"—that is, solutions must be measureable and based on research and best practices, but the must also be "reasonable," meaning they must meet the test of cost-effectiveness or cost-benefit.

Therefore that standard practice of charging premium prices for acoustical solutions has had to change.

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# Some implications of the Noise Policy Statement for England for the regulation and permitting of industry by the Environment Agency of England and Wales

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ABSTRACT

The Noise Policy Statement for England (NPSE), published by Defra in March 2010, describes a 'policy vision to facilitate decisions regarding what is an acceptable noise burden to place on society'. The publication of the NPSE coincided with the formal adoption and publication of the Noise Action Plans as required by the Environmental Noise (England) Regulations 2006 (as amended) and the Environmental Noise Directive. However, the potential implications of the NPSE go much wider. The Environment Agency in England is currently reviewing and rewriting its Horizontal Guidance for Noise. The updated guidance will be consistent with the aims of the NPSE, not least because the NPSE is largely consistent with the fundamental principles of the Environmental Permitting Regulations. This paper will discuss the aims of the NPSE and some less obvious and possibly surprising implications of the policy for industry regulated under an Environmental Permit administered by the Environment Agency. This work is likely to be of interest to consultants, planners and policy makers involved in Integrated Pollution Prevention and Control (IPPC, Directive 96/61/EC and the superseding Directive 2008/1/EC), and the control of environmental impacts of industrial activities.

## INTRODUCTION

### Regulation of noise by the Environment Agency

The Environment Agency England and Wales substantially first began to regulate the noise from industrial processes under the Integrated Pollution and Prevention Control Directive (IPPC Directive) in 2000. IPPC was introduced by the European Community (EC) Directive 96/61/EC on Integrated Pollution Prevention and Control. In England and Wales the Directive is implemented by the Pollution Prevention and Control (England and Wales) (PPC) Regulations 2000.

IPPC is a regulatory system that employs an integrated approach to control the environmental impact of emissions arising from industrial activities. It involves determining the appropriate controls for industry to protect the environment through a single permitting process. To gain an IPPC permit operators of industrial sites must show that they have systematically developed proposals to apply the Best Available Techniques (BAT) to pollution prevention and control, and that they address other requirements relevant to local factors.

In 2007, the Environmental Permitting Regulations combined The Pollution Prevention and Control (England and Wales) (PPC) Regulations 2000 and Waste Management Licensing (WML) Regulations 1994. The Environmental Permitting Regulations (England and Wales) 2010 were introduced on 6 April 2010, replacing the 2007 Regulations. This is the current method in England and Wales of implementing IPPC, Directive 96/61/EC and the superseding Directive 2008/1/EC.

### IPPC Horizontal Guidance Note for Noise Assessment and Control

The Environment Agency guidance relating to noise is the IPPC Horizontal Guidance Note for Noise Assessment and Control, which consists of H3 Part 1 and Part 2. This guidance is common across the Environment Agency, Scottish Environmental Protection Agency (SEPA) and Northern Ireland Environmental Agency (NIEA). H3 Part 1 was primarily focused on the legislative implications and requirements issues relating to noise. H3 Part 2 was mainly a background into the science of noise. Since the change in England and Wales to the Environmental Permitting regulations much of H1 Part 1 is no longer current, and so it has been withdrawn from the Environment Agency Website. However, at the time of writing, it is still available on the SEPA and NIEA websites.

## NOISE POLICY STATEMENT FOR ENGLAND (NPSE)

### Overview of the NPSE

The NPSE has a succinct '*Noise Policy Vision: Promote good health and a good quality of life through the effective management of noise within the context of Government policy on sustainable development*'. It consists of six brief paragraphs of text, a statement of three aims, five guiding principles for sustainable development, and four pages of explanatory notes. The NPSE separates policy from technical advice, which in principle allows more rapid changes to how noise is managed as knowledge about impacts develops, without the need to go back and review policy.

### Scope of the NPSE

Any organization that has a responsibility for managing noise is responsible for implementing the NPSE. It applies to all noise not simply ambient noise, with only workplaces excluded. The long term vision is supported by the following aims: avoid significant adverse impacts on health and quality of life from noise, mitigate and minimize adverse impacts on health and quality of life from noise, and where possible contribute to the improvement of health and quality of life.

### NPSE and the PPC Directive

The NPSE goes on to provide useful advice on interpretation of its aims, including the need to integrate consideration of the economic and social benefit of the activity or policy under examination with proper consideration of the adverse environmental effects. This is consistent with Directive 2008/1/EC, which is the latest edition of the IPPC Directive. The NPSE itself does not help clarify the conflict that is often faced between, for example, accepting that a particular development will have some negative impact on the noise climate of some individuals, although that impact is acceptable for the wider benefit to society.

### Applicability of NPSE to Scotland, Wales, and Northern Ireland

The NPSE applies directly only to England. However, its principles are consistent with the fundamental principles of Best Available Techniques (BAT), as described in the IPPC, Directive 96/61/EC and the superseding Directive 2008/1/EC, which applies across all European Union member states. In this way, the principles of the NPSE are applicable to Scotland, Wales and Northern Ireland.

### NPSE and the National Policy Statements (NPSs)

The six revised draft Department of Energy & Climate Change (DECC) National Policy Statements (NPSs) for energy infrastructure and accompanying Appraisals of Sustainability (AoS) are applicable in most cases to Wales as well as England. The most recent draft consultation documents contained the same three guiding principles as the NPSE. It is expected that they will remain in the final documents which are expected to be finalized and formally approved imminently at the time of writing this paper. These NPSs would then be used by the Infrastructure Planning Commission when it makes decisions on applications for development consent for nationally significant energy infrastructure. This is significant since this means that through the NPSs, all government departments will have endorsed these guiding principles.

### General applicability of the NPSE

There is a requirement for all regulating bodies at the time of rewriting any noise guidance to take into account the NPSE. There is also a requirement that any regulating body making any decisions that may have noise implications takes the NPSE into account. This would apply to County and Local Council Planning Authorities as well as national regulating bodies such as the Environment Agency. Therefore any council planning department should be able to demonstrate their consideration of this where noise is a consideration and that the decision is consistent with the guiding principles of NPSE. There is little evidence to date that the NPSE is being implemented in any substantial way by local authorities with few showing very much knowledge or understanding of the document.

### NPSE and assessing noise impacts of developments

Noise has tended to be considered almost in isolation from any benefits of the project to society as a whole. Also traditionally noise has been dealt with in such a way as to assess whether the negative noise impacts of a development project give an unacceptable increase in noise at identified receptors. Techniques involve comparing overall $L_{Aeq}$ with World Health Organization guidelines, or using BS4142 1997 to derive a Noise Rating to assess the likelihood of complaints. It could be argued that methods such as these satisfy the requirements of the first two aims of the NPSE i.e. *avoid significant adverse impacts on health and quality of life from noise*, and *mitigate and minimize adverse impacts on health and quality of life from noise*.

However, as traditionally applied these methods do not satisfy the requirements of the third aim of the NPSE, i.e. *where possible contribute to the improvement of health and quality of life*. It is not immediately apparent that older methods of demonstrating that noise level increases would have no unacceptable impact will not satisfy this requirement. This is because such methods will usually result in the opposite effect, which is continually raising ambient noise levels.

### Environment Agency and the NPSE

The Environment Agency considers that the NPSE is wholly consistent with the fundamental principles of Best Available Techniques (BAT) under the PPC directive, PPC regulations and Environmental Permitting Regulations and the other principles in the Environmental Permitting Regulations such as 'Appropriate Measures', which is essentially equivalent to BAT.

ENVIRONMENT AGENCY GUIDANCE FOR NOISE ASSESSMENT AND CONTROL

## Horizontal Guidance and NPSE

The Environment Agency England and Wales together with SEPA and NIEA currently has a project to rewrite the Horizontal guidance H3 for noise. The new guidance is designed to be sufficiently flexible to accommodate the different legislative regimes in the three governed regions of the UK. However, careful consideration also needs to be given in the update to the implications of the requirements of Noise Policy Statement for England (NPSE).

## The need for change

In the UK, there is often a fairly haphazard use of various British, European and International Standards, which leads to confusion and significant inconsistencies. There is repeated misapplication of the various standards, both through ignorance and deliberate acts to best achieve the particular requirements of a client or to demonstrate a point of view. For example, parts of guidance may be used by selectively highlighting features favorable to clients and ignoring footnotes and qualifying information. The Environment Agency considers that there is a clear need to move to a more consistent and objective way of assessing noise effects. The Environment Agency is currently producing guidance which seeks to consistently apply the various standards to ensure that objective noise measurements and impact assessments are carried out.

## Structure of the revised guidance

It is intended that the document be as future-proof as possible, whilst being non-legislation specific as far as practicable. To this end the revised guidance will be primarily a top level document that will outline general issues concerning noise, policy and legislation. Providing the technical detail for the H3 document will be a series of detailed noise guidance notes, referred to as the N-series. Specific topics covered include obtaining valid representative background ambient noise levels; competence of persons carrying out noise monitoring; noise assessments and noise management plans; assessment of tonality; and low frequency noise assessments.

## Method Implementation Documents (MIDs)

Historically the Environment agency has consistently received reports from operators and consultants where significant errors and bad practices have been carried out in the use of British, European and International standards. To aid removal of this it is proposed that where this is with commonly used standards that Method Implementation Documents (MIDs) are created that should significantly aid the interpretation and use of commonly used standards. This is a technique and format the Environment Agency has used successfully for many years for standard methods for the monitoring of pollutants to the environment, which include air and receiving waters. A visit to the Environment Agency website www.mcerts.net will give a good introduction to the workings of this method of guidance.

### Practical application of MIDs

Not all standards will require or have a Method Implementation Document, however where they are produced they will be regularly kept up to date as issues occur and apparent confusion seems to exist. They will also be used to eradicate instances of bad practice. Where a method implementation document exists it will be expected in all cases that it is used in conjunction with the Standard, and that where parts of a standard are no longer best practice, the MID may well specify an alternative, and in this case the technique in the MID must be used. In this way the standard as being applied will remain as up to date and current as possible.

### Improvement of health and quality of life

The issue highlighted earlier in this paper regarding custom and practice being to demonstrate that the increase in noise levels is acceptable and this leading to gradual increases in noise levels or creeping background. As eluded to earlier this is not consistent with the third aim of the NPSE, i.e. where possible contribute to the improvement of health and quality of life. It is essential that new H3 guidance and associated documents satisfies this aim.

### Addressing creeping background in practice

To satisfy the third aim it may mean that an industrial installation would need to be able to demonstrate that an expansion project had actively considered methods and designs that reduced the noise effects of the existing installation, for example by the location of a new building and the possibility of using it as a noise barrier to a sensitive receptor, or making a building on the new project slightly larger to house some of the existing equipment to reduce impact on sensitive receptors. Where many noise sources exist in close proximity, such as industrial sites it is important that when assessing the impact of a particular process, attempts are made to reduce noise levels such that future noise reductions from other sources will give an audibly noticeable and measureable reduction.

### Assessment of initial design targets

It is clear that not on all occasions is it practical for designs to produce an ever reducing soundscape, However it is currently extremely rare for this to be considered as an initial design target. The new H3 will set this initial objective where the initial design target for contribution at identified receptors will be 10dB below existing background. If this can be achieved with an initial design then there need be little further demonstration that the process is BAT and the design would be classed as broadly acceptable. If the initial proposed design is significantly higher e.g. 5 to 10 dB+ above background it is highly likely this will be deemed unacceptable.

### Demonstrating consistency with the principles of BAT and NPSE

There will then be the region between -10dB and +5 dB contribution or BS4142 Noise Rating where the operator and/or noise consultant will be required to do a rigorous justification that the option being proposed is BAT. The justification will need to detail options considered and there will need to be a sound justification why techniques which are available to reduce noise still further are not being adopted, on grounds of practicality and/or not economically viable. As noise contributions rise then the BAT justification will need to become more detailed and rigorous, and increasing cost of noise mitigation would be expected to rise proportionate to the increased effect on the receptor. This is consistent with both the principles of BAT and the third aim of the NPSE.

### Endorsement and acceptance of the guidance

One objective in the rewrite of the Environment Agency noise guidance is to obtain the endorsement of the professional bodies of noise consultants in England and Wales. One method to achieve this could be through a series of consultation with the appropriate members groups, such as the Institute of Acoustics. It is hoped that with the appropriate members bodies in agreement with the guidance and backing its implementation, to achieve consistency across its members and raise the standards across the acoustics industry in general.

The ultimate aim of the new Environment Agency noise guidance is to provide clear concise guidance that is easy to use. The aim is also to remain consistent with the same guidance across processes regulated by the Environment Agency, SEPA and NIEA. It would then be possible for acousticians to use the documents as the main reference documents for all noise monitoring and impact assessments.

## DISCUSSION

### Best practice for noise monitoring and impact assessment

It is envisaged that there will be a complete rebuild of the Environment Agency Noise Webpage. It is envisaged that if the appropriate professional bodies endorse the contents of the new guidance and associated documents that this could become the first place to visit to check current best practice for environmental noise monitoring and impact assessment.

### Sources outside the jurisdiction of the Environmental Agency

There are many noise sources that the Environment Agency do not regulate, such as wind turbines, road traffic, railway, and airport noise. To ensure that the website is used as first port of call it may be necessary to provide links to current best practice guidance for these topics on other organizations websites, such as IOA or Defra.

### Proformas for common procedures

On the Environment Agency noise webpage would be H3 noise guidance, up to date N series technical guidance notes and the current version of the required method implementation documents. There will be a link from the Environment Agency monitoring webpage to facilitate easy referral to the noise webpage rather than searching through the many facets of the Environment Agency website. It is also envisaged that there may be proformas for common procedures, such as producing a noise management plan.

### Extended application of the revised guidance

Since the documents will have implemented the NPSE in full it should be applicable to use the documents for noise measurement and assessments for other uses other than satisfying the Environment Agency, SEPA and NIEA, and should be selectively useful for supplying information to local authorities for planning etc. This may also ultimately lead to the guidance being used as a major reference by local authorities, and may lead to some consistency in information and requirements for noise across the UK.

## CONCLUSIONS

The Noise Policy Statement for England has created a need to review existing guidance and methods of noise assessment. This is particularly case with respect to the third aim, i.e. where possible contribute to the improvement of health and quality of life. This third aim is entirely consistent with the fundamental concept of BAT.

The Environment Agency is currently rewriting its noise guidance taking full consideration of the guiding principles of the NPSE. It is proposed that noise impact assessments would fall into three basic categories. The categories being:

i. broadly acceptable,

ii. unacceptable, and

iii. a category in the middle.

In the latter case, a rigorous demonstration would be required that the techniques employed for noise prevention and mitigation are appropriate.

There is a significant need to improve consistency in environmental monitoring and assessment of noise impacts, and to eradicate bad practices for whatever reasons they occur. At this time, there is a real opportunity to remove much confusion and prolific bad practice with the cooperation of a few key organizations, and come to a common objective understanding and route forward. It is hoped that the Environment Agency's reissue of its noise guidance can move the UK forward in a clear unified direction consistent with the NPSE, and lead to a gradual improvement in the noise environment.

## ACKNOWLEDGEMENTS

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# Protection against aircraft noise. Novella of the German law of October 31, 2007

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## PRESENT STATE

The „law of protection against aircraft noise" of 3/30/1971 in Germany contained limit values of 75, 67 and 62 dBA as protective zones, calculated to $L_{eq4,0\text{-}24h}$. These limit values served primarily for the settlement of zone planning and were not founded healthwise. The amendment of this law of 10/31/2007 occurred under inclusion of health points of view. The maximum values of this new law version were determined according to $L_{eq3,6\text{-}22h}$ for the day strain and $L_{eq3,22\text{-}6h}$ for the night strain. In addition to the judgment with the help of the night equivalent continuous sound pressure level the maximum level recorders $L_{max}$ has been considered as another important criterion.

**Table 1:** Emission Values Law of 10/31/2007

| | **Existing Airports** | **New Airports** |
|---|---|---|
| Day – Protection Area 1 | 65 dBA | 60 dBA |
| Day – Protection Area 2 | 60 dBA | 55 dBA |
| Night - Protection Area | 55 dBA<br>6 x 57 dBA | 53 dBA<br>6 x 57 dBA |
| **Starting 2011** | | **50 dBA**<br>**6 x 53 dBA** |

Beside the law of 1971 existed the air traffic-licensing order (LuftVZO) which apart from the attention of the law demanded a physical - technical certificate about the aircraft noise strain and also medical certificate about the possible health effects by independent consultants. These consultants according to the LuftVZO were obliged therefore legally to provide an objective scientific certificate about the state of the noise effect research which led of course over and over again to personalized discussions.

Therefore the scientists Prof. Dr. Griefahn (Dortmund), Prof. Dr. Jansen (Düsseldorf), Prof. Dr. Scheuch (Dresden) and Prof. Dr. Spreng (Erlangen), who represented different main focuses of the noise impact research (NIR), compiled in 2002 a comprising representation of the essential results of the NIR, the so called "Synopsis" (Griefahn et al. 2002) which were confirmed in the essentials after an examination in 2007 (Scheuch et al. 2007). The "Synopsis" was described on occasion of the ICBEN Congress at Rotterdam (Jansen et al. 2003).

The different protective aims health, nuisance, sleep disorders, communication disorders and recreational disorders were considered individually. The corresponding noise emission limits were implemented in gradated effect descriptions as „critical tolerance values (KTW)", „preventive approximate values (PRW)" and "quantitative threshold values (SW)" and recommended. As a judgment measure the continuous sound pressure level $L_{eq3}$ and the maximum level recorder $_{Lmax}$ were pulled up. In the novella of the law of 10/31/2007 became, as already mentioned, also $L_{eq3}$ and $L_{max}$ as judgment criteria applicable.

In Table 2 the suggested values are performed with different protective sighting and the day protection zones of the FlugLärmG, Table 2b contains those for the night. Moreover, judgment values of protective-destitute areas were derived. An essential advantage of the Synopsis is that medical, i.e. physiological, pathophysiological and clinical aspects as well as epidemiological, psychological and socially scientific findings were considered. Also different questions of noise physics were included under noise impact research points of view. Therefore it is an adequate complicated and comprehensive bio-psychosocial approach with objective judgment of the contribution of the single specialty disciplines around to the object of the noise effects. Another important advantage of this Synopsis and its grounds compared with many publications in this field is that results of other strain research fields, not only the noise, have been included. This concerns in particular the results of the stress research, the working strain research, knowledge of the psychosomatic medicine and results of the risk research in other areas. This concerns in particular the results of the stress research, the working strain research, knowledge of the psychosomatic medicine and results of the risk research in other areas. This concerns in particular the results of the stress research, the working strain research, knowledge of the psychosomatic medicine and results of the risk research in other areas. The difficulties of an isolated noise effect research and noise effect consideration, the lacking classification of noise-related study results in the medical and psychological research all together lead to misinterpretations and lacking acceptance.

**Table 2a:** Limitation values of the Synopsis and the aircraft noise law for the protection (in italics) as well as classification of everyday sound charges on the day (equivalent continuous sound pressure level) 1 = Synopsis, KTW: Critical tolerance value, PRW: Preventive appoximate value, SW: Threshold value, 2 = Aircraft noise law for the protection. A: Kerschsieper et al. (2006), B: Fischer (2007)

| **Level dBA** | **1 Synopsis**<br>**2 *Fluglärmschutzgesetz*** | **Classification** |
|---|---|---|
| 70 | 1 KTW Health | Work Social-Occupation [B] 69-76 dBA<br>Shopping Mall [A] 71-72 dBA<br>normal street traffic<br>Conversation raised<br>silent hairdryer (1 m of distance) |
| 65 | 1 PRW Health<br>KTW Considerable Nuisance<br>2 ***Day protection area 1* continued existence** | Commuter Train [A] 66-75 dBA<br>Radio/TV raised<br>Hotel at the Sea |
| 64 | 1 KTW Recreation | Dishwasher 63-71 dBA |
| **62** | **1 SW Health**<br>**1 PRW** Considerable Nuisance<br>**KTW Communication** | **Office [A] 62-64 dBA**<br>**Spare time social-occupations [B] 59-64 dBA** |
| 60 | *2* ***Day protection area 1* continued existence**<br>***Day protection area 1*** *New* | normal conversation |
| 59 | 1 PRW Communication | |
| 57 | 1 PRW Recreation | |
| 56 | 1 SW Communication | |
| 55 | 1 SW Considerable Nuisance<br>*2* ***Day protection area 1*** *New* | **Radio/TV household noise level**<br>Vacuum cleaner (10 m of distance) |
| 50 | 1 SW Recreation | light rain<br>quiet brook<br>smooth conversation |

Assigned were everyday events with her sound level recorders which were measured in average in each case for the duration of these events. They permit a better appraisal of the sound limitation values.

**Table 2b:** Limitation values of the Synopsis and the aircraft noise law for the protection (in italics) as well as classification of everyday sound strains at night (inside), see also explanation Table 1

| **Level dBA** | **1 Synopsis**<br>**2 *Fluglärmschutzgesetz*** | **Classification** |
|---|---|---|
| 50 | | Bird's twitter<br>(15 m of distance) |
| 40 | 1 KTW<br>*2* ***Night protection area 1*** ***continued existence*** | quiet radio music<br>Fridge |
| 38 | *2* ***Night protection area 1*** *New until 2010* | |
| 35 | 1 PRW<br>***Night protection area 1*** *New starting 2011* | very quiet<br>room ventilating fan |
| 30 | 1 SW | Whisper |

## FINDINGS AND DISCUSSIONS IN THE NOISE EFFECT RESEARCH AND POLITICS FOR LIMITATION VALUES OF AIRCRAFT NOISE WITH THE MAIN FOCUS HEART AND CIRCULATION ILLNESSES

After the announcement of the law in 2007 there have been other examination results of the NIR which mostly confirm to a great extent the limitation values of the law in 2007, but also in the partly political discussion further reductions were demanded.

In the beginning of 2006 Babisch presented an analysis of a total of 61 works published since 1968 to the statistical association between the acoustic strain by aerial noise, train noise and traffic noise on the one hand and blood pressure / hypertension as well as ischaemic heart illnesses on the other hand. In 14 examinations the blood pressure was measured differently of very exposed adults. In 4 examinations with the stronger exposed group this was slightly, at least systolically, but significantly higher than in the group of less exposed ($p<0.05$). The other studies produced partly contradictory results. To sum up, Babisch states that there would be no epidemiological proof of an increase of the blood pressure by traffic noise. This also applies to the hypertonia under acoustic strain. 18 works focused on hypertension as a medical diagnosis with differently strongly exposed people. While this with people with higher strain by aircraft noise was not even significantly higher than with the less loaded people, there was no clear picture for the traffic. Babisch states (*'Across all studies no consistent pattern of the relationship between the community noise and prevalence of hypertension can be seen.'* p 29) and *('a higher IHD risk was relatively consistently found in the studies')* the significance level also increases if residential situation, room layout and window aperture duration behavior are considered.

Recently Babisch & van Kamp (2009) published a meta-analysis to the relations between aircraft noise and hypertension. It is stated that the knowledge is lower to effects from aircraft noise than to street noise, because big clinical studies would be absent. There is a distinction between studies with regression beginning and with category beginning (see above). Sufficient qualitative proof is supposed that aircraft noise raises the hypertension risk with adults. This is concluded on the basis of the regression analysis. The given increase of the risk for the development of hypertension about 13 % per 10 dBA increase is based on the linear trend coefficient of 5 studies and is significant. With the categorical approach on the opposite no relevant relation were identified and from the authors – and this is generally an essential problem of different noise effect researches – was indicated on the differing noise data. It is seldom the actual measured equivalent noise level recorder, but in the single countries differently calculated noise descriptions with different "penalty kicks" for certain times of day or other conditions which serve as a base factor for the noise exposure. This also leads to the fact that in a regression beginning though these differences are reduced, but the statement, e.g. referring on 10 dBA, is only a calculated parameter. Thus it is also found out by the authors Babisch & van Kamp (2009) that is unclear whether the weighted noise indicators with surcharges reflect really adequately the physiological reactions. A whole series of concrete information would be necessary for a comparison and an evaluation of these noise parameters for example the frequency of the aircraft noise in certain times. It is stated by the authors Babisch & van Kamp (2009) that there is no simple, generalized or in certain times empirically supported dose-effect-relation for the coherency between aircraft noise and cardiovascular risk on account of methodical differences between the studies (noise appraisal, noise indicators, definition of the hypertension) and the absence by continuous or semi continuous noise data in the suitable publications. Therefore no clear result can be given to a possible effect threshold and that all descripted relations between aircraft noise and hypertonia are provisional due to the limitations of the corresponding studies. Further research studies are demanded to get a better evaluation of the risks.

To sum up, noise can lead like other unspecific stressors to a blood pressure raise and also hypertension. Nevertheless, a dose effect relation with a possible threshold is not academically provable in the area of traffic noise on the basis of the present study results.

Because there is a slightly raised risk under noise for heart circulation illnesses (in comparison to other risk factors), it is unfortunate that noise is not considered in the big national and international medical long time studies in the heart circulation area with the capture and observation by relevant risk factors.

## NOISE AND SLEEP DISTURBANCE

In the foreground of the research of the last years stood epidemiological examinations which concentrated nearly exclusively upon the long-term sound level recorders at night, because maximum level recorders and their frequency with this basic approach were not available to studies. Therefore are still relevant on the basis of the awakening reactions and the Cortisol - model derived limitation values of the maximum level recorder frequencies. (Basner et al. 2006, Griefahn et al. 2002)

Hume (2008) summarized into his overview seminar paper the results of the last years concerning sleep disorders by noise and gave a view of the next five years.

He stressed that the essential development of the knowledge in this area during the last five years are the results of the DLR study. The question of the long-term sound level recorder and single level recorders was also discussed by Hume. The use of single level recorders was above all also explained with the fact that the long-term sound level recorder had a too low verifiability for the affected persons. The dialogue and the revisability of defaults are an increasingly more important factor. This is also special difficulty of the use of the DLR results in general at airports and also for the airport of Leipzig/Halle. By Hume it was also stressed that in spite of all strains and work of the last years presently no statement are feasible to the long time effects of a disturbed sleep. He stressed the need from epidemiological as well as experimental research basic approaches. He also stated that hardly statements exist to the effects from sleep disorders of special vulnerable groups, in particular sick people, old people, or children.

In October 2009 were published "Night Noise Guidelines" by the WHO as an official document. This document is based on a research report of an expert's group. Already in 1999 the WHO published Guidelines for Community Noise, so the current recommendations are regarded complementary to this publication. Recommendations for the member states of 1999 are looked as still prevalid and relevant, although judgment values meanwhile have changed. The research report of a stated international expert's committee went through a WHO-internal and external investigation process (Babisch in 2009, 2010).

As from the WHO-regional manager for Europe Marc Danzon (WHO 2009) pointed out, these Guidelines are neither standards nor legally binding criteria. This guide is presented for the reduction of more negative health effects by night noise on the basis of expert's opinions and their scientific knowledge. The present level of knowledge is reported critically of the relations between night noise and health effects and still existing deficits of the knowledge are discussed. To these findings is a great consent given.

For the judgement of the night noise a night average level ($L_{night}$) is used. This also corresponds to the method usual in Germany to make a distinction between day and night level recorders. This $L_{night}$ is valid for eight hours. Maximum level recorders and their frequencies are not included as limit values or aim values, but by the derivation of $L_{night}$ they play a role (see below).

In the Community Noise Guidelines of 1999 appointment sound level recorders of 45 dBA were called outside flats and 30 dBA inside as target values to the avoidance of sleep disorders which should not be crossed. These target values are reduced with the current document to 40 dBA.

This is founded with new knowledge in particular by Passchier-Vermeer et al. (2002) and the DLR study (Basner et al. 2004) while the DLR study gets away all together with its very extensive results very briefly and that has identified just for the long-term sound level recorders at night no essential effect dependency. Therefore, particularly these studies, nevertheless, do not support the lead of this new directive limit value. Furthermore an interim target value of 55 dBA is given outside at night as a minimum aim if at short notice if 40 dBA are not to be reached.

It is pointed out the need of other examinations as well as some limitations, likewise the possibility of the Habituation and the unclear role of the day noise.

## NOISE, NUISANCE AND HEALTH

While the danger can have a medical, pathophysiological, being off sick character in the essentials, the considerable nuisance or considerable interference is marked by the fact that by noises conditioned, unwanted strong influences of human behavior patterns appear. This does not need exist objectively, the individual assessment, the individual experience identify substantially the occurrence of a considerable nuisance.

It is recognized that a zero nuisance as well as a zero portion of considerably bothered is not to be realized in the society. This is due to the fact, that

- there is a certain basic totality with negative information to all asked nuisance factors, a certain portion of people feels bothered by all they are asked,
- with questionnaire inquiries a trend towards the middle exists,
- dismay causes a different valency as a function of a variety of situative and personal factors of influence by which a total of a considerable width is to be registered by answer trends,
- the capture methods lead the subjective information mostly on a sound level recorder back, nevertheless, this is only one factor of influence on level recorder – nuisance - relations,
- the causing of negative feelings / interferences often is assigned to factors that resulted not of own responsibilities
- human life needs and generates certain sound level recorder areas and everybody is concerned by it.

On the other hand, a consideration with other risks and consequences has to occur by the assessment of nuisance which nevertheless is not an immediate job of a noise effect judgment.

With all discussions about the lead of sound level recorder – nuisance - relations is not to be forgotten that academically by the sound level recorder only a low part of the so-called variance of the relations is cleared up by sound level recorder and the information of nuisance. In the noise study in 2000 around the Zurich airport this is at most 15 % (Wirth 2004), meaning 85 % of the given nuisance by aircraft noise is not identified by the height of the sound level recorder. Generally the variance clarification of the relations nuisance sound level recorder is given between 9 and 33 % (among others Guski et al. 1999). This also means that different scientific efforts must be afflicted for the lead of level recorder-related limit values with considerable mistakes. However, assessment margins are settled nearly always with the sound level recorder. Nevertheless, there exist between sound level recorder and nuisance dose effect relations which are not distinct in other areas so clearly (Miedema & Vos 2003). However they are not - as this is often postulated - about all level areas linearly.

The results of scientific examinations to noise-conditioned nuisance and relevance vary between 50 and 70 dBA.

Despite the big variability of the examination results of numerous authors becomes evident that <u>nuisances appear between 50 and 55 dBA</u> and are probably <u>considerable from 60-65 dBA</u>, because between 28 % or 30 % of the exposed call themselves "extreme" or "strong" bothered.

## FINDINGS AND PROBLEMS OF THE NOISE EFFECT RESEARCH OF THE LAST YEARS

Studies of the last years underline

- The night aircraft noise plays a special role and shows more close relations with heart illnesses and circulation illnesses (e.g., hypertension) as day noise, relevant is the maximum level recorder.
- The day aircraft noise raises the occurrence of coronary heart diseases; nevertheless up to $L_{eq}$ = 70 dBA not significantly, but the relative trend already does begin with 60–65 dBA.
- Considerable nuisance: The level recorders sway to different studies around more than 10 dBA, newer examinations show higher percentages with lower level recorders, the common variance of level recorder and nuisance decreases during the last years clearly.

Still there is in the noise effect research a row of unsettled effect questions which are answerable only complex and interdisciplinary. A few examples are given:

- the effect from over all noise and the combination of different traffic noise sources,
- actual, academically sounded thresholds for disease genesis,
- the relations between considerable nuisances and diseases
- the effects of the noise on old people, sick people and concerning the health also children,
- the relations of the different noise measuring dimensions to the health.

The to be strengthened noise effect research has to dedicate more attention to the methodical problems in the planning as well as the interpretation. Population-related elevations are often supported by associations, interest representatives or lawyers. The result is the investigation of risk populations or from particularly health enthusiasts.

Among the rest this leads to the restrictions known in the social sciences of the quality of studies by "overreporting" up to the "Nimby effect" (Not in my backyard) or "Intra Class correlations" (families, association members, neighbors have often same answer trends). To this can be counted also other presented studies which were realized in the temporal connection with planned changes by airports. Conclusions for limitation values cannot be drawn from studies in such situations.

Also, the evaluation quality of many studies not seldom leaves much to be desired, because in the compulsion after the relevant results which should be quickly able of publication hardly concerning the contents sustentative selection procedures and arithmetic procedures are carried out. Here must be also classified the different noise quartile zones by Greiser & Greiser (2010) which enclose class sizes of 2 dBA to 13 dBA. With this false results are produced under effect aspects. This is also to be owed to the publication habits that above all "positive", "relevant" results must published, the so-called "publication-bias".

The mathematical-statistical treatment of data is means for the purpose of, condition for the interpretation of the results achieved are the assessment and the treatment of the input data and the assessment of the source data for the expected, academically to be founded effects. This can occur only according to scientific criteria hand in hand with the present knowledge of the medical and psychophysiological exposure research. Noise effect research has the job to forecast effects and not to produce isolated calculations. Adequate to the data level, most authors value their results in the scientific publications quite critically.

This critical attitude is to be missed in hearings very often. It is legitimate that in hearings and other procedures only the respectively discussed exposure factor plays a role. Nevertheless, conclusions infuse themselves not without a proper risk comparison.

On the other hand sound and noise characterizes human life. Sound is necessary, also noise, appearing everywhere, in his effect unspecific, the effect spectrum and the effect type is like many other factors of human life. Therefore it is necessary also with the traffic noise, and here especially the aircraft noise, to classify and put in relation this in the usual sound strains of the specific person. Besides this physical bases are to be considered, for example perceptibility with level recorder differences, logarithmic dependence of the effect from the sound level recorder, measurability among other things.

Essential defects in these discussions to results in the noise effect research are:

- lacking or missing consideration of the quality of the input data and the insufficient inclusion of confounders/additional factors of influence within the interpretation,
- non-consideration of the totality of the results and their evaluation, only "suitable" results are shown,
- overemphasis of multivariate statistical procedures without consideration of the quality of the input data and a missing sound interpretation, psychologically or medically, of the results,
- missing classification of the results in biological and medical processes by which only the relevance of the results becomes evaluable,
- non-consideration of knowledge from other strain areas of the person,
- missing classification in the usual sound strains of the person with which the test of the ecological plausibility is avoided,
- non-consideration of criteria of the environmental law and bases of the risk assessment, for example not the effect from environmental factors in itself is relevant, but its adversity, protective criteria are not able to considerate any single persons concern.

The science does not decide on limitation values, but has however to make clear the instep width and security of the knowledge to (adverse) effects.

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# Risk management for transportation noise

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## INTRODUCTION

Road transport, railway transport and aircraft operations are sources of substantial noise in urban areas and around airports. The noise levels due to road transport are increasing due to the growth in the number of both cars and freight vehicles. This growth trades off the technological achievements in motor and tire noise emissions. In addition, freight vehicles are less insulated. Road transport noise both in developed and developing countries makes it difficult to communicate when walking through a busy street. Noise due to railway transport stems from the friction between wheels and tracks. Railway noise sources include traction noise, rolling and squeal noise, and aerodynamic noise. Aircraft takeoffs are known to produce intense noise including vibration and rattle and the landings produce substantial noise in long flight corridors as well as when reverse thrust is applied. In general, larger and heavier aircraft produce more noise than lighter aircraft.

Environmental noise from transport is a global problem. There is a direct relationship between the level of development in a country and the degree noise impacting on its people. As a society develops, it increases its level of urbanization and industrialization and the extent of its transportation system. Each of these developments brings an increase in noise levels and related burden of disease. With no or weak intervention, the noise impact on communities will escalate (Figure 1). If governments implement only weak noise policies and regulations they will not be able to prevent a continuous increase in noise and its associated health effects.

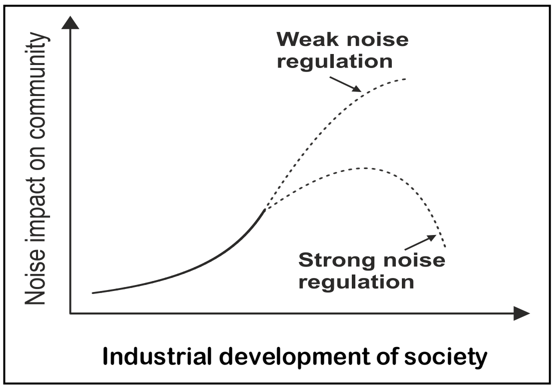


**Figure 1:** Relationship between noise impact and development

## NOISE RISK MANAGEMENT

The goal of noise risk management is to achieve and maintain low noise exposures such that human health (including well-being) is protected. The specific objectives of noise risk management are to develop criteria for maximum permitted noise exposure levels and to promote noise assessment and control as part of environmental health programs (WHO 1999, 2009). In achieving this goal a number of environmental management principles can be applied which include the:

- precautionary principle
- polluter pays principle
- prevention principle (WHO 1999).

The foundation for transport noise risk management is the government policy framework. Without an adequate policy framework, adequate legislation and adequate implementation and enforcement it is impossible to maintain a successful noise management program. A policy framework refers to transport, energy, planning, urban and regional development, land use planning and environmental policies. The goals are more readily achieved if the interconnected government policies are compatible, and if issues, which crosscut different areas of government policy are coordinated. An example for an integrated policy framework is the Environmental Noise Directive of the European Parliament and of the Council (EU, 2002).

## POLICY PROCESS AND STAGES IN NOISE MANAGEMENT

A general model for environmental noise risk management is depicted in Figure 2. The process outlined in Figure 2 can start with the development of noise standards or guidelines. Noise standards and model outputs or measurements may be considered in devising noise control tactics aimed at achieving the noise standards. Control tactics need to be enforced, and if the standards are achieved, they need continued enforcement. If the standards are not achieved after a reasonable period of time, the noise control tactics may need to be revised.

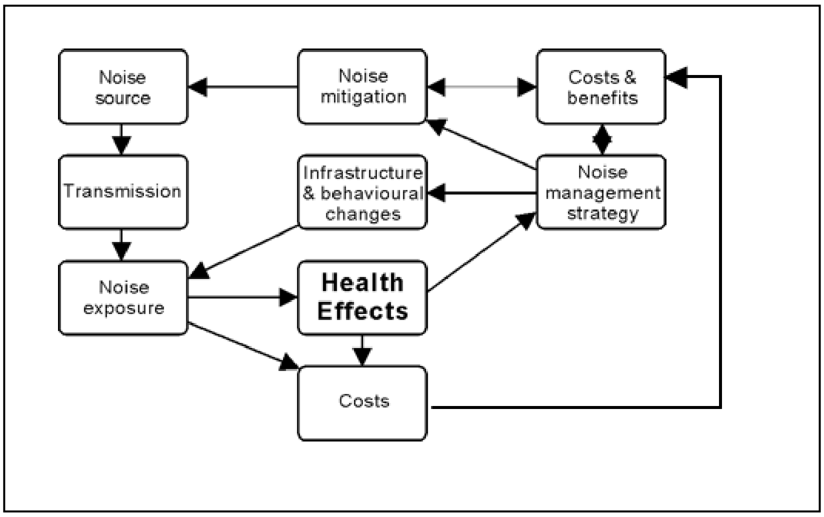


**Figure 2:** Model of policy process for community noise (adapted from WHO 1999)

National noise standards can usually be based on consideration of international guidelines, such as the Guidelines for Community Noise and the Night Noise Guidelines of the WHO (WHO, 1999; 2009). National criteria documents are also relevant if they base on exposure-response relations for the effects of noise on human health. National standards take into account the technological, social, economic and political factors within the country. Noise standards periodically change after reviews as conditions in a country change in the course of time, and with improved scientific understanding of the relationship between noise and the health of the population.

Figure 3 shows the various stages in the policy process and the policy player groups (stakeholders).

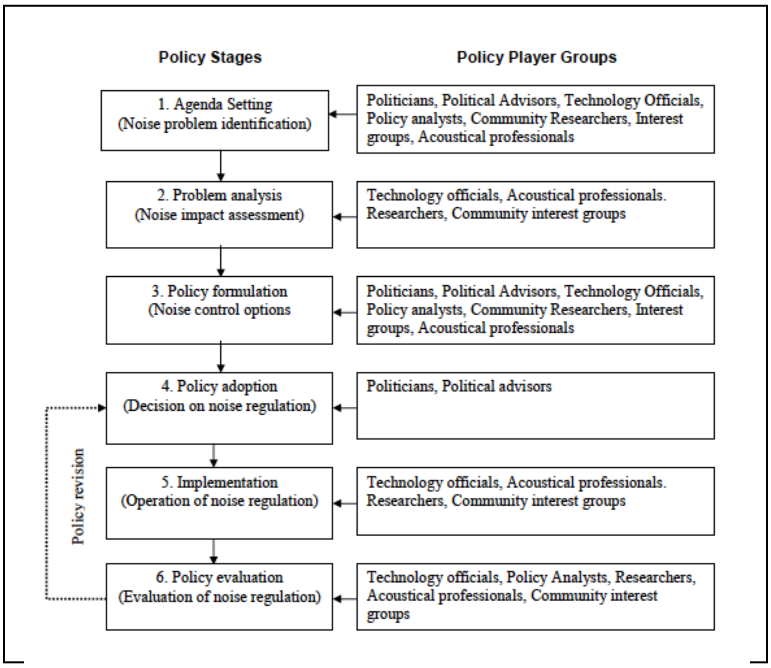


**Figure 3:** Policy stages and stakeholders (adapted from WHO 1999)

## NOISE IMPACT ASSESSMENT

Noise impact assessment needs the assessment of noise exposure levels and the estimation of the potential impacts of noise exposure. Noise exposure monitoring can be used to assess whether noise levels at particular locations comply with the standards selected, but given the cost and need for temporal and geographical extent of monitoring, compliance has to be determined largely through noise exposure modeling and noise exposure mapping.

## NOISE EXPOSURE MODELLING

Modeling is a powerful tool for the interpolation, prediction and optimization of control strategies. The accuracy of models available depends on many factors, including the accuracy of the source emissions data and details of the topography (for which a geographical information system may be used). For road noise parameters such as the number, type, the permitted speed of cars, and the type of road surface must be known. Similarly, for railway noise the number of trains per time unit, their speed, and the average length of noise events from a passing train are indispensable for noise exposure estimation. Aircraft noise parameters such as the number, type and speed of planes and the noise characteristics of takeoffs and landings must be known. Accurate forecasts of flight paths and variations in these are critical.

## NOISE EXPOSURE MAPPING

A crucial component of a noise risk management is a reasonable quantitative knowledge of exposure (see Figure 2). Basic information about the exposed population is needed for noise exposure estimates from road traffic, trains and aircraft movements. These and other relevant factors can be used to calculate noise exposures, which can be used to develop and implement noise management plans and environmental impact assessments. Exposure should be mapped for all types of transport noise sources.

## POLICY OPTIONS FOR SUSTAINABLE TRANSPORT AND NOISE REDUCTION

An integrated noise policy should include several control procedures: measures to limit the noise at the source; noise control within the sound transmission path, protection at the receiver's site, land use planning, education and raising public awareness. Ideally, countries should give priority to precautionary measures that prevent noise, but they must also implement measures to mitigate existing noise challenges and manage the growth of new ones. At-source measures that reduce overall emissions, traffic management and transport demand management measures are generally more cost-effective than noise exposure measures (noise barriers, building insulation) at the local level (Nijland et al. 2003; EC 2004; Larsen 2005; Ohm 2006; T&E 2011).

### Mitigation measures for road traffic noise

Measures that tackle the basic sources of noise are technical measures to reduce noise emissions from vehicles, tires and road surfaces. At-source measures at the vehicle level, however, have the disadvantage that penetration of the vehicle fleet takes several years for tires and almost a decade for motor vehicles (den Boer & Schroten 2007).

Traffic management includes measures to reduce the number of vehicles on the road, measures to smoothen traffic flow by road bypasses, roundabouts and intelligent tuning of traffic lights, speed limits and nighttime bans on trucks and lorries. A smaller number of vehicles reduces not only noise but also air pollutant and greenhouse gas emissions. Less cars plying on the roads also improve road safety. Specific traffic management measures may reduce noise levels between 2 and 7 dBA (Berndtsen et al. 2005). Traffic management measures involve only limited investments and have a direct effect because they can easily be enforced. However, the costs associated with potential travel time losses may be significant.

Transport demand management can reduce the number of vehicles by promotion of public transport, encouraging cycling and walking, applying congestion charges and parking management. In order to influence travel behavior an integrated approach should be applied (SDC, 2009). Such an approach considers the future needs of a community; behavior and trip generation; opportunities to make cycling, walking and public transport the modes of choice; needs for housing, schools, health centers, employment; good urban design which maximizes sustainable transport; and stakeholder information and participation. Urban design should consider the following hierarchy; (1) Pedestrians, (2) Cyclists, (3) Public transport use, (4) Specialist service vehicles (emergency, waste, etc.), (5) Other motor traffic.

In smaller towns of up to 10,000 dwellings, the majority of journeys should be feasible on foot or by bicycle. For larger urban areas, walking and cycling may need to be implemented by public transport. Prerogatives for convenient walking and cycling include: Direct, continuous, and uninterrupted links which are not accessible to motor vehicles to shopping areas and community facilities; improved road safety by pedestrian walks, lighting etc.; secure bike storage and rental facilities.

Encouraging a reduction in car dependency is a key component of promoting sustainable transport that emits less noise, air pollutants and greenhouse gases. This can be promoted by completely, or partially, car-free sites; limitation of car spaces; charge for residential car parking; restriction of car access and parking; low car flow favouring design of roads and streets; preferential treatment for eco-friendly, low-noise cars and scooters; provision of alternative access to local taxi services, home delivery vehicles, and on-demand public transport provision; and frequent, reliable and easily accessible public transport.

If at-source measures are insufficient to comply with noise limits, noise barriers and insulation of dwellings can reduce the propagation of noise. On average, noise barriers reduce noise levels by 3-6 dBA, depending on their design and height (den Boer & Schroten 2007). Roadside noise barriers are only useful for protection of dwellings close to motorways and bypass roads in urban and non-urban areas. For dwellings located farther away from motorways and bypass roads or at higher elevations roadside noise barriers do not provide a solution.

The average cost of a noise barrier is around € 300 per $m^2$, depending on its construction and the materials used (den Boer & Schroten 2007).

## Mitigation measures for railways noise

Possible solutions for railway noise mitigation include the lowering of radiation efficiency at wheels and rails; smooth wheels on smooth rails (optimized wheel design using damping rings, absorbers and optimized braking system – 4 -10 dBA - and track design via embedded rail systems, block and direct fastening systems - 5 dBA); rail grinding strategies (silent rail systems – 6 dBA, acoustical grinding – 10 -16 dBA); and appropriate maintenance of rails and wheels (Licitra 2006).

## Mitigation measures for aircraft noise

In many countries, the noise emission of aircraft is now limited by ICAO Annex 16, Chapter 3, defining maximum permissible sound limits under certain measuring procedures (ICAO 1993). Aircraft following the norms of Chapter 3 represent the state-of-the-art of noise control of the 1970s. On 1 January 2006, a more stringent noise certification standard - Chapter 4 was introduced, for new aircraft designs. Chapter 4 aircraft are at least one third quieter than those currently certified to the Chapter 3 standard (IATA 2007).

Most developed countries determine their noise control requirements on the basis of effect-oriented and/or source-oriented principles (Gottlob 1995; Jansen 1998; ten Wolde 1998).

The use of low noise aircraft may also be encouraged by setting noise-related charges (landing charges not only related to weight and capacity but also to noise emission). Examples of systems for noise-related financial charges are given in OECD (1991; see also OECD-ECMT 1995). Nighttime aircraft movements should be discouraged where they impact on residential communities. In Europe, there is a lot of debate among stakeholders about nighttime flight bans. Governments and aircraft carriers hold that nighttime flights are necessary while nongovernmental organizations claim that in spite of technological progress to reduce the noise from individual aircrafts people still suffer from the same or higher noise levels due to the increases in number and size of starting and landing aircraft (e.g. BANG 2004). Many of the Europe's leading business centers, including Berlin, Düsseldorf, Frankfurt, Hamburg, London-Heathrow, Munich, Zürich enjoy nighttime passenger curfews of 6-8 hours (HBA 2010). Of the approximately 300 US airports listed in the Boeing airports database, 73 are listed as having night-curfews (Boeing 2010). Airports without such regulations include Amsterdam, Barcelona, Madrid, Paris-CDG, and Tokyo.

PRECAUTIONARY MEASURES

With careful planning, exposure to noise can be avoided or reduced. A sufficient distance between residential areas and an airport will make noise exposure minimal although the realization of such a situation is not possible everywhere. Additional insulation of houses can help reduce noise exposure from airports. For new buildings standards or building codes should describe the position of houses and the ground plan of houses with respect to noise sources and also the required sound insulation of the façades.

Land use planning is a main tool of noise control. The necessary tools to be given to planners (and available to communities) include the calculation methods to predict the noise impacts; noise level limits for various zones depending on the type of buildings in these zones based on real or possible health impacts; and noise maps or noise inventories showing the existing noise situation.

### Education and public awareness

Noise abatement policies can only be established if basic knowledge and background material is available and people and authorities are aware of noise as an environmental hazard and the necessity to avoid and control noise. It is, therefore, necessary to include noise in school curricula and establish scientific institutes in universities and similar institutions, working on acoustic and noise control.

### Evaluation of control options

Unless legal constraints in a country prescribe a particular option, the evaluation of control options must take into account technical, financial, social, and health and environmental factors, as well as the speed with which they can be implemented, and their enforceability. Although considerable improvements in noise levels have been achieved in some developed countries, the financial costs have been high, and the resource demands of some of these approaches may make them initially unsuitable for developing countries and countries in transition. Planning to avoid transportation noise challenges is the long-term cheaper option as against fixing up problems once they occur. If developing countries put off considerations of transportation noise now because of other priorities, they will forego their current opportunities, and that will cost them dearly in the future**.**

There needs to be confidence that selected options are technically practical. A selected option must be able to be brought into operation, and maintain the expected level of performance in the long term with the resources available. The selected options must be financially viable in the long term. This may require comparative cost-benefit assessments of options. These assessments must include not only the capital costs of making an option operational, but also the costs of maintaining the expected level of performance in the long term.

The costs and benefits of each option should be assessed for social equity in relation to the potential for effects on people's way of life, community structures and cultural traditions. These may include disruption or displacement of residents, change of land-use, impacts on community, culture, and recreation. Some impacts can be managed, or resources or replacement uses can be substituted.

The costs and benefits of each option should be assessed for health and environmental factors. This may involve use of exposure-response relations, or risk assessment techniques.

Dealing with noise risks includes the acceptance of a risk. This is a dynamic process dependent on changing knowledge, attitudes, views, technical development, and costs of both studying the problem and implementing ameliorating solutions (Babisch 2002).

## CONCLUSIONS ON NOISE RISK MANAGEMENT FOR TRANSPORTATION

Noise from transport – road, rail and aircraft – can have serious impacts on human health in terms of cardiovascular effects, annoyance, sleep disturbance, cognitive effects, physiological and, particularly in developing countries, physical effects. Current transport policies often compensate increasing use of vehicles by growing road building, which leads to urban sprawl. Such policies are unsustainable. Four different routes for policy options to achieve sustainable transport with less noise (and air pollution and greenhouse gas emissions) are discussed in this paper: At-source measures, traffic management, transport demand management and measures to hamper noise propagation. The most cost-effective options are the first three, which can provide more transport sustainability. The fourth option is most expensive, only partially effective, and does not contribute to transport sustainability.

Successful noise management should be based on the fundamental principles of precaution, the polluter pays and prevention. The noise abatement strategy typically starts with the development of noise standards or guidelines, identification, mapping and modeling of noise exposures in communities. The powerful instrument of modeling must be transparent, allow scenario testing by planners and the community, and need ideally be validated by some monitoring data.

Noise control should include measures to limit the noise at the source, control within the sound transmission path, protection at the receivers' site, land use planning, education and public awareness raising. With careful planning, exposure to noise can be avoided or reduced.

The control options should be evaluated while taking into account the joint technical, financial, social, health and environmental factors of concern. Risk-cost-benefit relationships as well as the cost-effectiveness of the measures must be considered in the perspective of each country's social and financial situation.

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# Integrating noise into government appraisal and cost benefit analysis in the UK

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## INTRODUCTION

This paper seeks to explain how noise is being integrated into Government appraisal and cost benefit analysis in the UK. Economic evidence and analysis play a central role in the development of evidence based policy by providing appraisal tools which can quantify the effects of noise. In this way it is possible incorporate noise into decision making along with the other costs and benefits which a particular policy option may involve. The UK government seeks to disseminate these tools as widely as possible so that they are available not only for policy appraisal but also to highlight some key questions for use in further research into the impact of noise.

The first part of this paper gives a brief overview of the UK Government's theoretical and practical approach to creating the noise appraisal tools which we currently use. The second section outlines the results of the latest research into specific impacts of noise and how that work can be integrated into public decision making.

## VALUATION METHOD

The Interdepartmental Group on Costs and Benefits Noise Subject Group (IGCB(N)) was established in 2007 with the remit to develop a robust economic methodology to value noise. The IGCB(N) then looks to disseminate these methodologies for use in appraisal across all UK Government policies. The IGCB(N) is an interdisciplinary group of analysts from across most major UK Government departments.

In August 2008 the IGCB(N) published its first report which conservatively valued environmental noise pollution in the UK at £7-10bn per annum (IGCB(N) 2008).

This report also established the 'impact pathway' approach as the central framework for developing appraisal tools for use in the evaluation of UK Government policies. This approach follows noise from its source, through propagation, and through its effect on the ambient noise level, to the final impact on the exposed population, which allows the effect of the additional noise to be quantified, and where possible assigned a monetary value for use in Cost Benefit Analysis.

Noise is commonly defined as any unwanted sound. The individual making the sound (through driving their car) will not view it as noise as such, but third parties in the exposed population able to hear it will. It can be argued that noise is an example of market failure if noise is considered as a negative externality (defined as a cost imposed upon a third party by the producer/consumer of a good or service where the third party had no say in the decision to produce/consume). Noise fits quite well into this aspect of economic theory, as noise is usually generated as a by-product of other economic activity, such as transport used in order to use services. The effects of this noise on the exposed population (third party) effectively amount to a cost which when monetized can be used as an estimate for the cost to society of environmental noise pollution. Figure 1 below shows this concept diagrammatically.

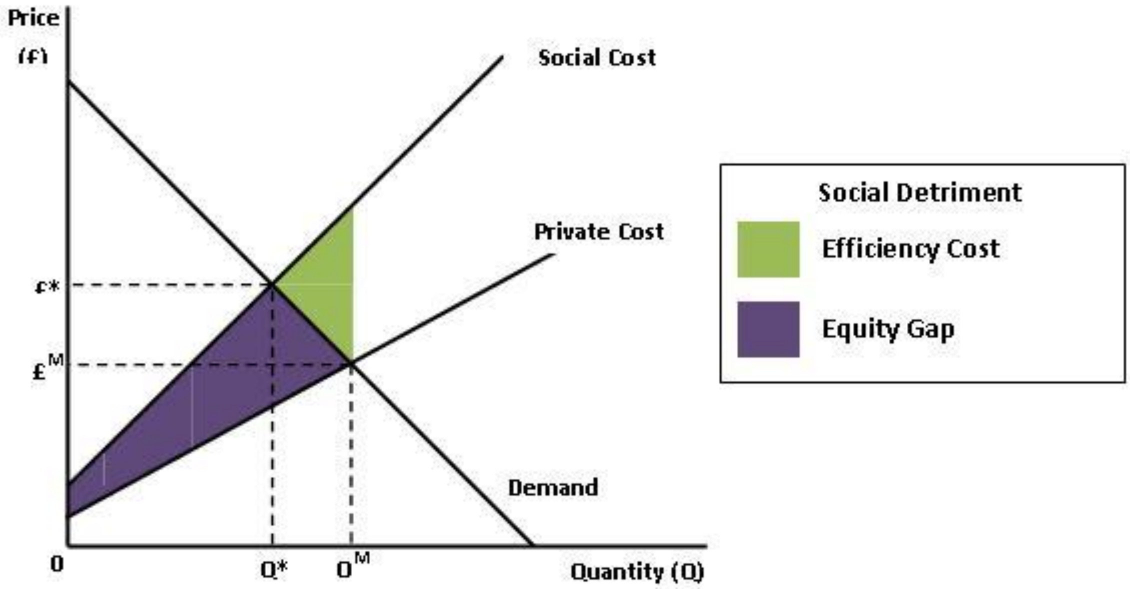


**Figure 1:** Negative Externality Diagram

The above diagram illustrates a classic negative externality. In this case the social cost of producing/consuming noise creating good/services is greater than the private costs paid by the producer/consumer. This difference between the private cost and the social cost can be seen as the value of noise pollution (the shaded area in Figure 1), this is the cost which is being inflicted on the exposed population. This is an equity problem as it is unfair that these people should bear the cost of an economic decision they were not consulted on. It is also an inefficient use of resources, as when the externality exists, the private cost, and therefore price, of those goods/services is lower than the true cost to society, and demand is consequently higher at that price. This results in overproduction ($Q^*$ - $Q^M$ in Figure 1), as the costs of providing this output exceed the benefits, resulting in deadweight welfare loss (the green area). These resources could be used far more efficiently elsewhere in the economy.

While this demonstrates the detriment from noise, in order to inform decisions it is necessary to assess the evidence on the scale of the problem. If the detrimental effects of noise can be quantified and monetized, we can essentially estimate the value of the colored area in Figure 1. For presentational reasons the IGCB(N) first report split noise pollution down into four key effects which could then be analyzed separately in detail. These effects were on:

- Public amenity, reflecting the public's conscious reaction from noise exposure (both positive and negative), this was estimated at £3-5bn per annum.
- Health, including long term health effects such as changes in mortality and temporary health effects such as acute myocardial infarction (AMI), the value of these effects was estimated at between £2-3bn.
- Productivity, which largely concerns sleep disturbance due to noise causing next day fatigue, or sleep deprivation leading to an increase in accidents in the work place, leading to health costs, this pathway, was estimated at approximately £2bn per annum.
- Environmental impacts, such as impacts on breading patterns and damage to natural ecosystems.

Estimation and valuation of the public amenity costs of noise has been considered in transport appraisal since 2005. Monetization has been carried out using a hedonic pricing model which estimates the difference between house prices as a result of different noise levels. The Department for Transport (DfT) uses this methodology to calculate its Webtag valued, which are used in the appraisal of road and rail projects (Department of Transport 2011). This methodology assigns values for a per decibel change in noise levels per household, making it relatively simple to quantify the amenity effect of a given project which is expected to lead to a change in noise levels of a given amount (these values are shown below in Table 1).

**Table 1:** Valuation of Amenity and Health effects of noise (Mid-point marginal values are used for each volume range (there is a full list of per decibels in the IGCB(N) second paper)

| Volume $L_{aeq}$, 18hr dBA | Cost per household per dB change | |
|---|---|---|
| | Health value | Amenity/Annoyance costs |
| 55-60 dB | £2.70 | £40.00 |
| 60-65 dB | £10.47 | £53.20 |
| 65-70 dB | £15.71 | £66.40 |
| 70-75 dB | £29.62 | £79.60 |
| 75-80 dB | £41.01 | £92.80 |
| 80-85 dB | £53.60 | £98.00 |

In its first report IGCB(N) prioritized the investigation of health effects. Defra, on behalf of the IGCB(N), commissioned experts Dr Bernard Berry and Dr Ian Flindell to undertake a review of research into the links between noise and health (Berry & Flindell 2009). The report produced several key findings: Quantifiable empirical evidence was found linking noise to Acute Myocardial Infarction (AMI) (heart attacks), and other cardiovascular illnesses. Evidence was identified linking noise with other health effects such as; annoyance, mental health, hypertension (high blood pressure), cognitive development in children, and hearing impairment, though monetary valuation of these impacts was not judged to be sufficiently robust to include these effects in appraisal methodology at present.

In response to this work the IGCB(N) published its second report (IGCB(N), 2008). This paper incorporates Acute Myocardial Infarction (AMI) into the monetary valuation methodology of noise using the Babisch does-response function (Babisch 2006) recommended by Berry and Flindell. This was a major step forwards in the valuation of environmental noise, and this relationship was also formalized into an appraisal tool valuing the effect per household of a per decibel increase in environmental noise levels, which can be used together with the amenity appraisal tool. These values are shown in Table 1 below. The IGCB(N) second paper also agreed dose response functions linking environmental noise with hypertension and sleep deprivation: For each 1 dBA $L_{den}$ increase in exposure per household above 55 dB, there is an expected increase in hypertension of around 16 new cases per 1,000 households. For sleep disturbance, an increase in night time noise levels from 70 dB to 71 dB, would lead to 22 additional cases of sleep deprivation per 1,000 households. At the time we did not have the methodology for using these relationships to estimate the monetary value of these changes.

Once this was agreed amongst IGCB(N) members, these appraisal values became supplementary departmental guidance, and are now classified as appraisal best practice guidance. This represents significant progress over the past three years in which IGCB(N) has existed. However, the IGCB(N)'s remit is to ensure that appraisal is based on the best available evidence, and seeks to keep up to date with advancements in academic work on noise.

## FURTHER RESEARCH

Despite this progress there remain notable gaps and uncertainties in the evidence of the impacts of noise. One of the main criteria when selecting research areas is the potential impact of noise in that area, as it makes sense to estimate the areas with the largest impact, so that the most important effects are included first. In September 2010 Defra commissioned research on some key gaps in the evidence base relating to; health, amenity, and productivity. Most of this work seeks to quantify impacts to so that they can be compared to the other impacts to determine their magnitude, and then incorporated into appraisal guidance. The impacts that were researched and the findings are explained in more depth in the following sections.

### Quantifying the link between health effects and environmental noise related hypertension

The IGCB(N) second paper introduces the dose-response relationship between environmental noise and hypertension, for example, a 1 dBA rise in noise levels affecting 1,000 households would lead to 16 new cases of hypertension in the exposed population. This methodology can be used to estimate the quantitative (but not monetized) impact of noise on hypertension. However, to determine how large the impact of hypertension is relative to other health effects it is useful to monetize these effects. The impact pathway approach functions by identifying end points of emissions to which monetary values can then be ascribed. In the case of hypertension, these end points are the additional risks of secondary health outcomes that arise from or can be exacerbated by hypertension. These final health outcomes can then be quantified and monetized to provide an estimation on the marginal impact of noise on health in this pathway.

This project was undertaken by the Health and Safety Laboratory and was completed in April 2011 (Harding et al. 2011). After conducting a literature review the main health effects from hypertension were; stroke, ischaemic heart disease, chronic renal failure/end-stage renal disease, dementia, pregnancy complications, eye conditions, and sexual function. It was necessary to prioritize three health effects to move forwards for monetary valuation, this decision was based on the strength of the evidence on the relationship between the health effect and hypertension, and the likely cost of the health effect monetized. Ischaemic head disease, stroke, and dementia were prioritized.

The final health effects were quantified in terms of Quality Adjusted Life Years (QALY), the Department for Health's recommended figure in appraisal of health effects, this QALY has a value of £60,000 ($97,000), which was then multiplied by the risk of hypertension associated with environmental noise and the risk of each health outcome associated with hypertension. This was then applied to data collected during Round 1 noise mapping (a requirement of the Environmental Noise Directive (2002/49/EC)), to estimate the impact of road and rail traffic noise. The total impact of road traffic noise was valued at £1,023m (£277m for AMI, £300m for stroke, and £446m for dementia). However, this only covers approximately 40 % of the UK population as mapping was only done for the 23 largest agglomerations in England, although this is the 40 % of the population most exposed.

IGCB(N) are currently in the process of developing a response to this research to suggest how and if this evidence will be reflected in appraisal guidance. Furthermore, this work has also highlighted some further gaps in the methodology. Most significantly, the current methodology only considers the impact of noise on the exposed population without hypertension (by estimating the additional number of cases of hypertension due to noise), and if the effect of noise causing increased blood pressure on those with pre-existing hypertension was included the estimate of the impact would be more accurate. This, however, would require more research on the relationship between environmental noise and systolic blood pressure. Also, this report only values the cost of morbidity/mortality to the individual due to these health effects. The costs to society in terms of health and social care in 2008 were estimated to be £8bn for coronary heart disease, £5bn for stroke, and £23bn for dementia, so a proportion of these costs should be included at this level.

## Quiet areas

Having access to somewhere quiet is important: a 2009 ICM Poll found that 91 % of respondents in the UK thought that existing areas of quiet need protecting. Furthermore, the Environmental Noise Directive stipulates that member states must protect existing quiet areas in urban agglomerations. Much of the literature on noise focuses on the detrimental effects of noise rather than on the benefits of quiet, which may be greater than avoiding the costs of high noise levels. This piece of work attempts to assess the relative importance of quiet against other issues through attempting to estimate the monetary value to society of quiet areas.

Defra commissioned URS Scott Wilson Ltd to undertake the project, and the final report was completed in April 2011 (Rowcroft et al. 2011). The project's ultimate aim was to produce a methodology for valuing quiet areas. This is difficult because many areas that are considered quiet are often parks or other urban open spaces where quiet is just one of a number of benefits drawn from the space. Moreover, many of the benefits are not easy to separate from quiet (e.g. an escape from hustle/bustle or a place for rest/relaxation). The key question to answer is therefore how much greater is the value of an area which is quiet, relative to an identical area which is not? Disaggregating the benefits (and hence value) of quiet areas is a key challenge, as people typically do not pay for access to these places. The paper also sought to investigate how people's valuation of a particular area changed in response to increasing environmental noise levels through asking how their usage of an area would alter in response to changing noise levels.

The report began by conducting an extensive literature review on the available evidence in order to build on the existing valuation studies in this area. This is a relatively new area of research (although now rapidly gaining in prominence) so there was a relatively small number of valuation studies found suitable for use. In light of this, the report suggested three ways in which to use the available information to value the benefits of quiet: using a range of green space values as a proxy for quiet areas to identify an upper range estimate of the value of quiet areas, estimating the opportunity costs of maintaining undeveloped sites, and making use of existing values for noise disturbance in the home (using DfT's WebTAG values which are derived from a study on house prices). Some primary research conducted as part of the project found that one third of respondents would vacate an open space if continually subjected to loud traffic noise. An illustrative case study on a park in Westminster, used both willingness to pay figures available for parks offering similar amenities and primary survey data to estimate the value of quiet within the green space. This was estimated to lie between £284,130 and £1,782,660 per year (this range in value is principally driven by the willingness to pay estimates used). Applying this approach on a national scale, the total value of quiet in open spaces could be up to £1.4bn per annum. Whilst quiet is only one component of the total economic value of these open spaces, this result implies that the value of all the open spaces in the 23 agglomerations would be very large, with quiet being a significant component in that value.

This report, on what is essentially a new area of study, makes a clear step forwards, as not only does it move us to the frontier of the available evidence, it has also identified a methodology, and also filled some important evidence gaps. This is a relatively unresearched area, and this report makes a very useful contribution to the literature. Furthermore, the paper makes some recommendations for further work including: identification of the criteria/attributes that define different types of 'quiet areas' or spaces people value specifically because they are quiet, assessing the value or ranking of quiet relative to other properties that characterize 'quiet areas', better defining the relationships between the different types of quiet areas and the value of benefits obtained (i.e. is there a threshold of noise beyond which the benefits of quiet are lost?), determining the willingness to pay for quiet areas and how this changes in response to changing noise levels, and conducting trial studies of quiet areas using noise mapping/sound measurements and data on user numbers to identify empirical relationships. In sum, more work is needed to improve the consideration of acoustic factors when assessing the value of open spaces, as quiet is an implicit feature in how people value open spaces which needs to be done before a more formal appraisal tool can be created.

### Estimating the productivity impacts of noise

The IGCB(N) first paper estimated that the productivity costs of environmental noise were roughly £2bn per year, however, this indicative estimate was based on a single link through sleep disturbance. However, noise can affect productivity through several different pathways such as: Noise causing sleep deprivation leading to tiredness, causing lower next day effectiveness. Higher noise near schools can lead to reduced academic performance, resulting in lower lifetime earnings. Also, the health effects of noise may lead to absence from work, which results in lower productivity as output falls. Defra commissioned Transport Research Laboratory (TRL) to conduct a literature review to assess the available evidence (Morgan et al. 2011). The main pathways which noise affects productivity are shown below:

- Noise → Sleep Disturbance → Tiredness → Accident/Inefficiency
- Noise → Stress → Short-Term Health Effects → Absence from Work
- Noise → Distraction → Lower Educational Attainment → Lower Lifetime Earnings
- Noise → Distraction in Workplace → Reduced Output

The report found that it would be possible to produce an appraisal tool linking sleep deprivation to a loss in productivity, though there are some issues with the dose-response relationship employed, as much of the evidence is based around self reported sleep disturbance which does not always correlate well with lab based measures of sleep quality. Also, noise events rather than $L_{den}$ measures of noise have been shown to be a more accurate measure of awakenings. Productivity loss through sleep deprivation has been estimated at 0.8 % of GDP in Australia in 2004, and in Japan in 2003 it was estimated to cost the economy $30.7bn per year, these reports suggest that it would be possible to produce a high level estimate for the UK, and the results may be quite significant relative to the existing monetized impacts of noise.

The report also highlighted the potential loss in productivity from noise induced health effects. For example, if someone was affected by noise induced hypertension then they may be less productive and absent from work which would result in a productivity cost. At present we value the cost to the individual of noise in terms of QALYs but not the cost of the lost output that worker has not produced due to the illness.

## CONCLUSIONS

While the evidence base which underpins noise appraisal has developed rapidly a number of notable gaps and uncertainties remain before it can be fully reflected in policy decisions. The next step for IGCB(N) is to produce a response paper which will determine what can be taken from these research projects and integrated into our existing appraisal tools.

This evidence has however identified a wide range of additional areas and questions to continue to develop this area. The key areas where future work/research would, in our view, add the most value are:

- The relationship between noise and systolic blood pressure, so that the effect of noise on those with pre-existing hypertension can be estimated.
- Quantification of the link between sleep disturbance and reduced next day productivity, and also the link between lower academic attainment and lifetime earnings.
- Determination of consumers' willingness to pay for quiet areas, and how this changes in response to increased noise levels.
- The effect and final impact of hypertension (caused by noise) on End-stage Renal Disease.

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# The importance of clear policy objectives when managing noise

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## INTRODUCTION

This paper considers the issues associated with the objectives of noise management. What exactly is the purpose of noise management and how might having a clear policy purpose assist the decision making about noise management? This paper examines noise policy objectives and shows that it is possible to have a clear policy that would enable effective noise management to occur.

## A POLICY OF NOISE REDUCTION

The management of noise has occurred for thousands of years. One of the earliest references to noise control can be found in the Holy Bible, where in the first book of Kings, Chapter 6, Verse 7 it states:

> *In building the temple, only blocks dressed at the quarry were used, and no hammer, chisel or any other iron tool was heard at the temple site while it was being built.*

King Solomon did not want the environment of the site of the Temple to be degraded by the sound of hammers and chisels. Consequently, much of the fabrication of the temple occurred off site. A noise control measure that is still in use to this day.

Ever since then, there have been numerous examples of noise management including the use of straw to reduce the sound of horses' hooves on cobbles.

Such measures have sought to reduce noise, so it could be argued that the key policy outcome of noise management should be a reduction in noise level.

But when has the noise been reduced or sufficiently reduced? It is very well known that it is possible to achieve a measurable reduction in noise level, but in fact it may be a reduction that cannot be perceived. So is that an acceptable reduction in terms of meeting a policy of 'noise reduction'? Probably not.

So, that means that to meet the policy requirement of noise reduction, the reduction achieved has to be perceptible. But what is an acceptable reduction – 3 dB / 5 dB / 10 dB / 20 dB – or is the policy only achieved if the reduction is such that in the end there is no noise – i.e. it becomes inaudible?

## MANAGING THE EFFECTS OF NOISE

The actual noise level itself is only a surrogate for what we are trying to quantify in noise policy. It is the management of the effects of noise on people (primarily) that is at the heart of noise policy. For the most part, therefore, the level of noise expressed in terms of a noise indicator or noise exposure is a measure that aims to describe the effects of that noise.

This suggests that any noise policy should concentrate on the effects of noise rather than simply the level of noise or noise exposure.

The challenge we have is that humans have a wide range of sensitivity to noise. Figure 1 shows a familiar meta- analysis of community reaction to road traffic and aircraft noise.

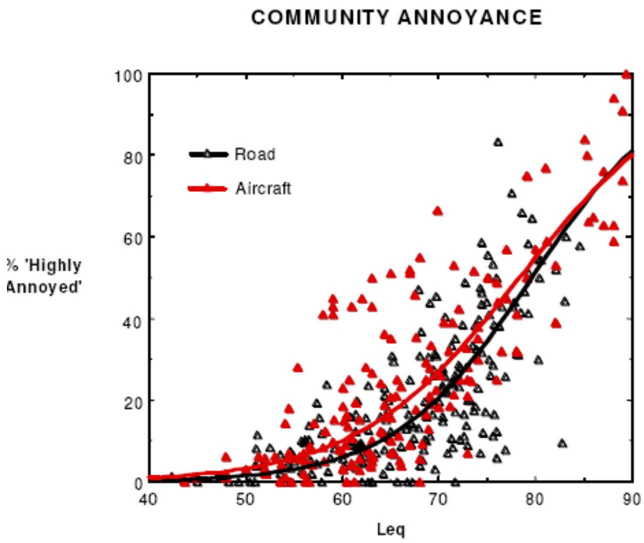


**Figure 1:** An example of a meta-analysis of community reaction to noise (after Schultz)

There are several policy messages that can be drawn from this figure:

- At any given noise exposure there is a large range of response;
- At the higher and lower noise exposure levels typically encountered in the environment, there is neither 100 % highly annoyed or 0 % highly annoyed;
- Increasing noise exposure brings an increased percentage of highly annoyed.
- The response depends on the source.

Thus setting any policy in terms of a noise exposure that should not be exceeded will almost certainly still leave some groups of people highly annoyed and hence suffering the consequences of that effect. Is that an appropriate policy outcome? Furthermore, almost certainly it would be inappropriate to have a single limit for all sources, because, again as is well recognised, the effect of noise is dependent on the source. Therefore, there would have to be different limits for different sources.

## LAND USE PLANNING POLICY

Over the years, noise policy has included statements such as:

*The aim of this guidance is to provide advice on how the planning system can be used to minimise the adverse impact of noise.*

This is not an unreasonable policy aim, given that keeping to a minimum the adverse impact of noise also keeps to a minimum the number of people adversely affected by it.

But – what is meant by minimum?

Taken literally – minimum means no people adversely affected. And unless a motorway, for example, is several kilometers away from any residential premises, the only way to secure no adverse affect would be to close the road.

So, in reality, ‘minimum’ actually means the ‘minimum possible’ resulting in some form of compromise or a balance.

The land use policy guidance example quoted above, in full states:

*The aim of this guidance is to provide advice on how the planning system can be used to minimise the adverse impact of noise without placing unreasonable restrictions on development or adding unduly to the costs and administrative burdens of business*

Thus for that policy, the compromise includes taking account of burdens on business.

In England the concept of Best Practicable Means (BPM) also exists where:

- “practicable” means reasonably practicable having regard among other things to local conditions and circumstances, to the current state of technical knowledge and to the financial implications; and
- the “means” to be employed include the design, installation, maintenance and manner and periods of operation of plant and machinery, and the design, construction and maintenance of buildings and structures;

In some circumstances, the test of BPM applies only so far as the action is compatible

- with any duty imposed by law;
- with safety and safe working conditions; and
- with the exigencies of any emergency or unforeseeable circumstances.

These two examples show that noise management policy can be interpreted as being about balance. But how should decisions be made about striking the balance? At what point does the costs and burdens to business render noise mitigation not possible, or does the benefit to society of the noise making activity become so great that noise impact is an undesirable but an acceptable price to pay for that benefit? Alternatively, are there any circumstances where the noise impact is so great that regardless of the benefit of the noise making activity the development should not proceed?

So, although the policy appears clear, its detailed application leaves much capacity for interpretation.

## THE POLICY IN DIRECTIVE 2002/49/EC

In Europe, environmental noise management is set out in Directive 2002/49/EC, the Environmental Noise Directive (END). Close examination of the END indicates that there are two underpinning policy themes:

Firstly, there is the well-known statement (in the English translation):

> *The aim of this Directive shall be to define a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to exposure to environmental noise.*

The second underpinning policy aim of the END is set out here:

> *This Directive shall also aim at providing a basis for developing Community measures to reduce noise emitted by the major sources, in particular road and rail vehicles and infrastructure, aircraft, outdoor and industrial equipment and mobile machinery.*

So an interpretation of the first policy is that there should be a focus on a ‘common approach’ and, indeed, this has occurred over the last few years with the work being carried out to develop a common noise assessment method to be used in noise mapping.

That policy also implies a desire for common approach with regard to actions. Again evidence of this work can be seen through European initiatives in controlling the noise emission from sources, and, the second policy aim reinforces that desire.

However, it is a highly debatable point whether it is appropriate to seek to have a common approach to ALL aspects of noise management across Europe. Detailed consideration of this point is only now emerging, and it is inevitable that questions of subsidiarity will be raised as the debate progresses.

But what, ultimately is the policy goal of the END. An answer can be found in the first statement. The policy wishes not only to “reduce” the harmful effects of noise but also to:

- “avoid” or “prevent” **any** harmful effects due to noise.

There is no other context for the END. Therefore, it could be argued that the implementation of the END will only have been a success if there are no harmful effects from environmental (transport) noise. This is a very laudable goal, but with the current society structure, it is a highly ambitious and a probably impossible outcome.

The END appears to treat noise in isolation so that it can be perceived that there is no sense of balance in the ultimate aim, which makes it more difficult for policy makers to promote.

## NOISE POLICY IN ENGLAND

In England, a balance has been included in the Noise Action Plans established by implementation of the END:

> *The Government intends that the END Action Plans will assist the management of environmental noise in the context of Government policy on sustainable development. Within this policy context, this Noise Action Plan aims to promote good health and good quality of life.*

Here, context is set out, with its implied balance. It also focuses on the effects of noise rather than stating that a particular noise level or noise exposure has to be achieved. This Noise Action Plan aim comes from the Noise Policy Statement for England (NPSE) that has been prepared in part to add clarity in policy, which as described previously is not always apparent.

The NPSE applies to all forms of noise including environmental noise, neighbor noise and neighborhood noise. It sets out the long term vision of Government noise policy:

> **Promote good health and a good quality of life through the effective management of noise within the context of Government policy on sustainable development.**

This long term vision is supported by the following aims:

> **Through the effective management and control of environmental, neighbor and neighborhood noise within the context of Government policy on sustainable development:**
>
> - **avoid significant adverse impacts on health and quality of life;**
> - **mitigate and minimize adverse impacts on health and quality of life; and**
> - **where possible, contribute to the improvement of health and quality of life.**

The vision is the ideal and is the ultimate policy objective – effectively no adverse effects on health and quality of life as a result of noise exposure – not dissimilar from the END policy. However, the aims reflect the reality of today's society, which include:

1. Some noise making activities are essential for society to function. At present, we cannot remove all adverse impacts of noise.
2. Some significant adverse impacts may still be unavoidable.
3. Some adverse impacts may still be unavoidable
4. Good management can facilitate improvements to health and quality of life.

The NPSE uses the phrases, "significant adverse" and "adverse" and their interpretation can be assisted by considering established concepts from toxicology that are currently being applied to noise impacts, for example, by the World Health Organisation. They are:

*NOEL – No Observed Effect Level*

This is the level below which no effect can be detected. In simple terms, below this level, there is no detectable effect on health and quality of life due to the noise.

*LOAEL – Lowest Observed Adverse Effect Level*

This is the level above which adverse effects on health and quality of life can be detected.

Extending these concepts for the purpose of the NPSE leads to the concept of a significant observed adverse effect level.

*SOAEL – Significant Observed Adverse Effect Level*

This is the level above which significant adverse effects on health and quality of life occur.

As with the noise limit point made earlier, it is not possible to have a single objective noise-based measure that defines SOAEL that is applicable to all sources of noise in all situations. Consequently, the SOAEL is likely to be different for different noise sources, for different receptors and at different times. Therefore, it is inappropriate to have specific SOAEL values in the NPSE.

At its most fundamental level the policy is clear and simple. It does not quote guideline, target or limit values for the reasons set out above. It does, though, in any situation, provide the three clear policy aims to be considered in terms of noise management:

- Is there, or is there likely to be, a significant adverse impact on health or quality of life (well-being)? If yes can this be avoided in the context of Government Policy on sustainable development?
- Is there, or is there likely to be, an adverse impact on health or quality of life (well-being)? If yes, to what extent can this be mitigated or minimized in the context of Government Policy on sustainable development?
- Is there an opportunity for improving health and quality of life through noise management in this situation in the context of Government Policy on sustainable development? If yes, take it.

## CONCLUSION

A clear policy vision and supporting aims thus enables effective noise management decisions to be taken. The acoustician will need to think about each situation encountered because there is not a simple formula that can be applied to determine the appropriate outcome. Fundamentally, though, the process is straightforward as clear policy objectives, properly applied, should lead to a society where good health and good quality of life has been promoted (and hopefully ultimately achieved) through the effective management of noise.

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The Noise Policy Statement for England can be downloaded from
http://archive.defra.gov.uk/environment/quality/noise/policy/documents/noise-policy.pdf.

## DISCLAIMER

The sentiments expressed here are those of the authors and not necessarily those of their colleagues or employers.

**The final paper was not available at deadline.**

# Contribution to meet new requirements in Brazil for protection of bedrooms against external noise: an easy, low cost and reliable measurement in dBA to estimate sound isolation performance of windows

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ABSTRACT

Hundreds of thousands of the so called "acoustic windows" have been installed in dormitories, by the users, in cities like São Paulo, Brazil, reinforcing the ones furnished by building constructors. This means a strong dissatisfaction of significant part of the population with their noisy bedrooms, affecting comfort and health, to the point of pushing them to provide a solution by their own expenses. This is undoubtedly a social, health and economic problem being presently discussed. A new Brazilian standard poses the requirement for building constructors to previously evaluate how noisy is the outside of bedrooms and living-rooms and to specify appropriate Rw-Noise Reduction Indexes, for the windows. They complaint about complexity and costs of measurements and ask for simple means of previously evaluate the solution to be adopted. The research reported in this article proposes a method of performing the evaluation in dBA, comparing the results with the standardized measurement of Rw.

# The assessment and control of road traffic noise: A comparison between Irish and Australian policy

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## ABSTRACT

To address the problem of environmental noise, the European Commission issued Directive 2002/49/EC which requires relevant authorities to prepare strategic noise maps and action plans. While the Directive has had a significant impact on EU Member States, outside of Europe it has had no discernable impact. This paper presents a review of the approach adapted in Ireland to the management of road traffic noise and compares it to current practices in Australia; with particular emphasis on New South Wales, i.e. we compare the approaches on an EU Member State (Ireland) with a non-EU State (Australia). In Ireland, the National Roads Authority (NRA) has been defined as a noise mapping body charged with the responsibility of preparing strategic noise maps for the national road network in accordance with the Directive. Subsequent to the transposition of the Directive, the NRA issued guidelines on the treatment of noise for national road schemes in 2004. In Australia, the NSW Office of Environment and Heritage (OEH) recently released its updated Road Noise Policy document outlining a policy for acceptable road traffic noise limits. This paper summarizes the strategies adopted by both jurisdictions and lessons learnt from each approach are explored, leading to suggestions for potential improvements to the current noise assessment and control strategies of both States.

## INTRODUCTION

In 2002 the EU issued Directive 2002/49/EC requesting Member States to develop strategic noise maps and noise action plans. The first phase of noise mapping is now complete and the results have highlighted the extent to which Europeans are exposed to environmental noise, with road traffic noise identified as the most dominant source of environmental noise throughout Europe today. One primary aim of the Directive was to establish a common approach to the management and assessment of environmental noise across Europe. This saw the development of the universal noise indicators $L_{den}$ and $L_{night}$. $L_{den}$ is the day, evening, night noise indicator and includes weighting the evening and night periods to represent a value for overall annoyance, while $L_{night}$ (with no weighting) represents an indicator for sleep disturbance. These indicators were chosen with the aim of reducing large volumes of information to a simple indicator assembly that is easy to handle, but still meaningful (Cvetkovic & Prascevic 2000). The Directive did not however stipulate any guideline limit values for environmental noise as it was felt that this would not be possible given the large differences in scale and comprehensiveness of implemented noise measures throughout the different Member States.

The Directive has had a significant effect on the assessment and management of road traffic noise in Ireland and this is likely to be the case in many other Member States, particularly those States who have no national noise prediction method. Currently, more than 28 % of EU Member States now use the $L_{den}$ indicator for road traffic noise (CEDR 2010). Outside the EU however, the terms of the Directive are not applicable and non-EU Member States are free to adopt alternative approaches. As such this paper compares the approach to the assessment and management of road traffic noise of one EU Member State (Ireland) to that of a non-EU Member State (Australia).

## IRELAND

EU Directive 2002/49/EC was transposed into Irish legislation through Statutory Instrument No. 140 of 2006 (the Environmental Noise Regulations (EPA 2006)). These regulations identify the Irish National Roads Authority (NRA) as a noise mapping body with responsibility for the preparation of strategic noise maps for major national roads. The NRA's primary function, under the Roads Act (1993) is to secure the provision of a safe and efficient network of national roads. For this purpose it has the overall responsibility for the planning and supervision of construction and maintenance works on these roads.

As part of phase one of the NRA's environmental integration model (EIM), the NRA published guidelines for the treatment of noise and vibration on national road schemes (NRA 2004). Prior to the publication of this document there were no Irish guidelines governing the assessment of noise associated with either new or existing roads. These guidelines provide explicit guidance on how noise should be addressed during the development stages of a road scheme.

### NRA noise guidelines

The NRA Noise Guidelines set out the procedure to be followed in respect of the planning and design of national road schemes. The guidelines are not mandatory but are recommended to achieve appropriate consistency with respect to the treatment of noise and vibration during the planning and construction of a road scheme. For full details the reader is referred to (NRA 2004) but some of the main points of the document may be summarized as:

- All new national roads schemes should be designed, where feasible, to meet a design goal of 60 dB $L_{den}$ (free field residential façade criterion).
- Predictions should be made according to the UK's CRTN calculation methodology.
- An adapted version of the CRTN shortened measurement procedure is presented to determine baseline measurements.

It has been noted that, due to the lack of detailed planning guidance relating to other sources of noise, the approach and limits set out by the NRA have been applied to other scenarios (EPA 2009). For example, planning conditions relating to new residential developments alongside existing roads may call for the façade level to be limited to the 60 dB design goal described in the NRA Guidelines. This approach is inappropriate and uses the Guidelines in a context for which they were not designed. It would seem that, in the absence of relevant guidance and legislation, the NRA Guidelines are becoming a *de facto* standard in Ireland. The NRA's construction noise and vibration limits have also been reproduced extensively in quite unrelated contexts (EPA 2009).

It is also important to note where the NRA Guidelines sit in respect to the overall planning process. It is the competent authority (which may be An Bord Pleanála[1] or the local authority in the case of national road project development) who decides whether an EIS produced for a national road development adequately discusses the likely changes in noise climate and consequent effect on occupiers of noise sensitive locations. The competent authority does this after taking account of the views of the public and other specialist bodies required to be consulted and after having regard to relevant publications, including those of the National Roads Authority.

## Mitigation measures

In order to meet the design goal of 60 dB $L_{den}$, the NRA recognized that noise mitigation measures, where feasible, would be necessary to achieve this goal at noise sensitive locations. However, it should be noted that mitigation measures were only deemed necessary when the following three conditions were satisfied at designated sensitive receivers:

a) the combined expected maximum traffic noise level, i.e. the relevant noise level, from the proposed road scheme together with other traffic in the vicinity is greater than the design goal;

b) the relevant noise level is at least 1 dB more than the expected traffic noise level without the proposed road scheme in place;

c) the contribution to the increase in the relevant noise level from the proposed road scheme is at least 1 dB.

These three conditions were primarily adopted to ensure that mitigation measures arising out of the assessment process were based upon the impact of the scheme under consideration (NRA 2004). However, there are a number of situations that may arise where the application of the three conditions may not be appropriate. These conditions have the potential to allow development to proceed in locations where noise is already deemed high without requiring noise mitigation. This is particularly relevant to road scheme upgrades where the existing noise levels can already be quite elevated.

## Strategic noise mapping and action planning

The first phase of noise mapping, in accordance with Directive 2002/49/EC was successfully completed in Ireland in 2007. In total this included one agglomeration (Dublin), one airport and approximately 600 km of major roads outside Dublin and involved five noise mapping bodies. These noise maps describe the level of noise exposure of approximately 1.25 million people. Road traffic noise was identified as the most dominant source of environmental noise in Ireland, both within and outside the agglomeration.

Following the development of strategic noise maps, Member States must ensure that noise action plans are then developed. The Directive describes action plans as plans ‘designed to manage noise issues and effects, including noise reduction if necessary’. In Ireland, noise mapping bodies are not automatically identified as action planning authorities. Instead noise mapping bodies create noise maps on the behalf

[1] The Irish national planning appeals board, set up to operate an open and impartial planning appeals system.

of the relevant action planning authority, usually the local County Council. For the first phase a total of 22 local authorities developed noise action plans for major roads within their jurisdictions (Shilton & Stafford 2009) based on maps developed by the NRA.

The Regulations define the Irish Environmental protection Agency (EPA) as the national lead authority to supervise and guide the various noise mapping bodies and action planning authorities. Further, action planning authorities should primarily design their action plans with the twin aims of: (1) avoiding significant adverse health impacts from noise; and (2) preserving environmental noise quality where it is good. Guidance notes are offered on the preservation of quiet areas, quiet areas in open country, planning, sound insulation etc. Two types of noise levels are also proposed; onset levels for the assessment of noise mitigation and onset levels for the assessment of noise preservation where they are good.

In general action plans prepared for the first phase did not report forecasted improvements in noise levels or exposure statistics associated with the adoption of proposed mitigation measures. A general discussion of possible mitigation measures was presented instead. Commonly proposed mitigation measures include the construction of new road schemes to bypass towns, promoting public transport, traffic calming measures, resurfacing roads and petitioning the EU to set more stringent vehicles and tyre noise regulations.

AUSTRALIA

In Australia, road traffic noise is regulated by the various state and territory governments. This is in contrast to the regulation of international aviation noise which is regulated by the Commonwealth Government. As a consequence of there being multiple regulatory authorities, there are a mix of noise indices ($L_{10}$ or $L_{eq}$) as well as varying times for delineating day and night (6 or 7am/10pm). Whilst there may be some fundamental differences in setting criteria between the various jurisdictions, the actual outcomes and management procedures are generally fairly similar. For the purposes of this paper a comparison has been done to New South Wales, the most populous state in Australia with almost 7 million residents and is home to 4.7 million registered vehicles out of an Australian total of 16.1 million (ABS 2008, 2010).

### New South Wales

In NSW noise criteria for a range of activities is set by the Office of Environment and Heritage (OEH). The Road Noise Policy (RNP) is the relevant document for assessing major roads and sets the criteria listed in Table 1.

**Table 1:** NSW noise level criteria

| **Activity** | **Assessment Period** | |
|---|---|---|
| | **$L_{eq\ (15\ hour)}$ Day** | **$L_{eq\ (9\ hour)}$ Night** |
| New Roads | 55 dBA | 50 dBA |
| Redeveloped Roads | 60 dBA | 55 dBA |
| Objective for Existing Roads (where no redevelopment is planned) | 60 dBA | 55 dBA |

In addition the RNP sets criteria for sensitive receivers such as churches and school classrooms. To protect the amenity of low noise environments the RNP also seeks to restrict the relative change in noise levels to either the criteria or no more than 12 dBA, whichever is lower.

Road noise criteria in NSW is non-mandatory, however strong justification in terms of reasonableness and feasibleness must be demonstrated if these levels are not met by new road projects. Whilst noise goals are set for existing roads, in practice these levels are exceeded by a large number of high volume roads, particularly in Sydney.

The Roads and Traffic Authority (RTA) is the State Government agency with the responsibility for managing the network of major road in NSW including noise issues. For smaller projects this agency is a self-determining body, however, for larger projects approval lies with the NSW Department of Planning and Infrastructure (DP&I). The RTA interprets the requirements of the RNP and outlines how it will meet its obligations in the Environmental Noise Management Manual (ENMM). This document provides a number of practical scenarios to assist engineers and network planners in meeting noise objectives in a consistent manner. In addition this document establishes the framework for the Noise Abatement Program (NAP).

## The Noise Abatement Program

The NAP was originally developed from a 1995 State election commitment to address impacts to residences which had a pre-existing road traffic noise problem. There was no commitment to annual expenditure, however historically the RTA spends around AU$3m pa. The NAP is a prioritized retrofit program that seeks to fund solutions to existing road noise problems. It does not provide funds to mitigate noise from new projects. The ENMM provides guidance on how a priority system should work and how to select the most appropriate treatment options. In practice, the large majority of treatments provided are ‘at-receiver’ mitigation such as architectural treatment of windows and doors or in some cases construction of courtyard walls. In urban areas, noise walls are not a usual option because of access issues.

Currently the RTA caps treatment at around $25,000 to those residences that are deemed fit for mitigation work. There are no internal noise goals to meet for existing residences, and the RTA makes no guarantee in regards to meeting specific internal noise levels.

## The Noise Abatement Database

As a consequence of managing complaints, the RTA undertakes a great deal of noise monitoring to establish whether a property qualifies for inclusion on the NAP. Initial screening may involve examining known noise levels at nearby properties, examining traffic volumes and speed or by undertaking short term (15 minute) noise monitoring during high traffic periods. If the screening indicates the property may qualify for inclusion on the NAP database then 7 day monitoring will be undertaken.

To qualify for inclusion on the NAP database a receiver must exceed the criteria by at least 5 dB during either the day or evening periods. There are additional qualification criteria for entry on the NAP database including a residency requirement. In recognition that home owners make strategic decisions in purchasing homes, the RTA generally excludes homes that have been owned by the residents for less than 7 years. Also excluded are residential dwellings that trigger a need for increased architectural acoustical designs under the Infrastructure State Environment Planning Policy (ISEPP).

The NAP database is a priority based listing that places the most affected properties at the top of the list. Properties stay on this list until treated, however, in practice those that just manage to qualify for inclusion on the NAP database will never be treated because they will be queue jumped by more highly exposed residences. Depending on funding available, the level at which treatment is made available varies year by year. Residences on the top of the list are typically 10 -15 dBA above the noise objectives i.e. an $L_{eq(9h)}$ night time level of 65 - 70 dBA.

As of February 2011 the NAP database has measured noise levels for 715 properties including 555 in Sydney. In addition more than 500 km of noise barriers have been entered on the database.

**The Infrastructure State Environmental Planning Policy (Infrastructure SEPP)**

Traditionally, residential development in Sydney has often occurred along busy transport corridors. Whilst in many cases the residential development occurred when the corridor carried low levels of traffic, natural growth has often resulted in the residences now adjoining heavily trafficked high speed transport routes. In other cases, residential development may have occurred due to low land costs or proximity to a center with services and public transport. Regardless of the original reasons for the development occurring, the quality of life of the residents can be adversely affected unless appropriate site layout, design or other mitigation measures to minimize noise and air quality impacts have been integrated into the development.

The NSW Government has recognized that in order to provide environmentally sustainable and affordable housing for a growing population with smaller household sizes it would require renewal of existing urban areas. Moreover, while this new housing should ideally be located near a center, within walking distance of frequent public transport, this should only occur where adverse noise and air quality impacts of the road can be minimized and good quality high amenity residential developments are created.

To facilitate these objectives the Infrastructure SEPP was gazetted to allow effective delivery of infrastructure across the State. Key objectives of this planning policy were to:

- protect the safety and integrity of key transport infrastructure from adjacent development; and
- ensure that adjacent development achieves an appropriate acoustic amenity by meeting the internal noise criteria specified in the Infrastructure SEPP.

In summary, this policy effectively sought to place responsibility for managing transport noise impacts on new developments on to the residential developer and provide a mechanism to ensure that only acoustically acceptable residential developments were constructed in areas of high transport noise. A major initiative of this SEPP is that for the first time a planning instrument in Australia has established internal noise levels (35 dBA for bedrooms and 40 dBA for other habitable rooms) in new residential developments planned along identified transport corridors.

To support the Infrastructure SEPP, the NSW Department of Planning released *Development in Rail Corridors and Busy Roads – Interim Guideline* in 2008. This document was developed with significant input from acoustic experts and other government agencies, and provides guidance on building design, internal layout and architectural principles to achieve an acceptable internal acoustic environment as well as synergies in addressing air and noise impacts. The Guideline also provides general guidance on strategic planning for Councils and other government agencies, or private proponents investigating possible locations for new residential and other sensitive development that require development approval. In addition, it provides guidance on site selection to reduce or avoid the need for mitigation measures for new residential (e.g. single/dual occupancy, multi-unit, etc.) dwellings.

## DISCUSSION

It would seem that policy relating to the assessment and management of road traffic noise in Ireland has largely been driven by EU legislation however a comparison with that of NSW shows that there are similarities in some critical aspects of road traffic noise management. Examples include the use of non-mandatory criteria and feasibility conditions associated with mitigation measures. However, in other management areas very different approaches have been used. Table 2 presents the commonalities of the two jurisdictions along with areas which were not found to have comparable road traffic noise management tools.

**Table 2:** Comparison of noise management tools used by Ireland and Australia

| Noise Management Tool | Ireland | NSW |
|---|---|---|
| Noise Policy | ✓ | ✓ |
| Guidelines | ✓(1 document) | ✓(2 documents) |
| Non Mandatory Criteria | ✓ | ✓ |
| Level of Mitigation based on being Reasonable and Feasible | ✓ | ✓ |
| Additional Consideration of Low Noise Environments | ✓ | ✓ |
| Noise Maps | ✓ | × |
| Action Plans | ✓ | × |
| Preventative Strategy | × | ✓ |
| Noise Abatement Program | × | ✓ |
| Funding Model | × | ✓ |
| Database of Impacted Residences and Measures Implemented | × | ✓ |

For Ireland, there are lessons to be learnt from the Australian policy, particularly in the establishment of a Noise Abatement Database which would support the development of strategic noise maps and action plans.

With regards to noise mapping, NSW has closely followed this EU initiative, particularly that of Dublin, and while there has been recognition that such an exercise would provide useful information there has been some reluctance for any particular Government agency to take responsibility to develop a full scale noise map. Noise mapping is seen as a useful modeling tool to predict impacts associated with changes to the road network and modal changes in freight transport. It is likely that in the near future that NSW will continue to monitor the success of noise mapping in Europe, particularly the development of Action Plans. Should NSW decide to implement noise mapping, the extensive NAP database would provide an excellent calibration tool.

The Infrastructure SEPP is proving to be an excellent preventative measure in NSW and ensures that developments which may have a nominally noisy façade, still manage to provide acceptable internal noise levels. Its adoption by Irish regulators would address the issue of the NRA Guidelines being used as a de facto standard and could form part of a national noise action plan.

## CONCLUSIONS

Both Irish and NSW jurisdictions have committed considerable resources to develop road traffic noise management measures. This review has found that these approaches are virtually exclusive in the information and responses they result in. Because there is minimal overlap in the approaches, the authors believe that there would be no conflict or duplication in continuing the respective management directions whilst incorporating aspects of the other jurisdictions management procedures. Moreover, it is seen that this amalgamation of approaches would: enhance the level of scientific input; develop preventative strategies; improve network planning by the addition of a predictive ability; and deliver more measurable outcomes.

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# Management for wind turbine generated environmental noise

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## INTRODUCTION

One of current environmental problems in Latvia and in the world, that still is under evaluated and waiting to be resolved, is environmental noise. The process of management of environmental noise in Latvia was started in 2004, when Latvia joined the EU and the requirements of corresponding directives were incorporated into state's legislation. However, even now on national or municipal level the administrators of resources fail to see the noise pollution as a matter of priority.

One type of environmental noise sources that should be managed, are stationary facilities, among them wind energy facilities. The activity of wind turbine generates tonal, broadband, low frequency and impulsive sound (Rogers et al. 2002). The level of noise generated by wind energy facilities depends on the parameters of the wind turbine, the distance to the receiver, air absorption, orographic conditions, meteorological conditions as well as sound obstructions.

The noise generated by the wind energy facilities may cause social behavior disorders in the receptor; for example, discontent, aversion and annoyance, or it can advance disorders of speech, sleep or intellectual work performance (Rogers et al. 2002). In practice it is believed, that with appropriate wind park layout planning the negative influence of the noise can be reduced, although the perception of the noise and consequently the level of its impact is determined by various subjective factors. Whether the sound becomes undesirable depends on the type of sound, the sensitivity of hearing and on other factors that may affect every particular person. In sensitive people the agitation caused by the noise might cause stress induced illnesses. Still, part of the society considers the infrasound to be one of the main problems caused by the wind parks, even though so far no evidence of its negative influence has been found (Wind noise turbine conference 2011). Due to the above mentioned subjective considerations, it is impossible to clearly determine the effects of noise generated impacts and their accompanying reactions.

The development of wind parks has become one of the most disputable questions also in Latvia. Imperfections in legislation and in concepts of planning, as well as insufficient communication among involved parties about the development of wind parks and their diverse impacts, have increased the emergence of negative attitude in part of the society as well as popular protests. In year 2010 several constitutional law-suits related to the impact of wind park development on society´s health and rights to live in a congenial environment, have been adjudicated. Problematic situations of the development of wind turbines have been widely reflected in mass media and several research studies about the future development have been started.

### The use of wind parks in production of renewable energy recourses in Latvia

The need to construct wind parks is determined by the necessity to develop the use of renewable energy thus enabling the sustainable management of natural resources and ensuring state´s energetic independence from foreign countries. The potential of wind energy in Latvia is determined by its location and meteorological conditions.

Considering the wind velocity and the orographical aspects, the most suitable territories for development of wind parks in Latvia are in the west coast (see Figure 1).

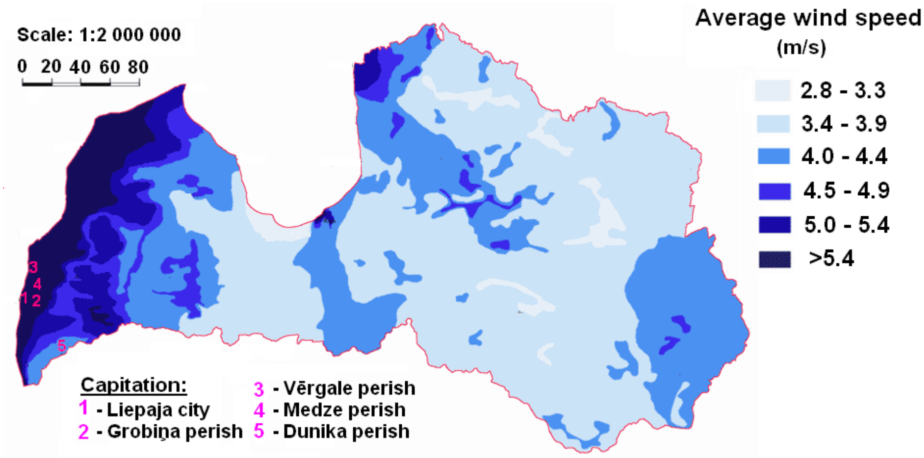


**Figure 1:** The average wind velocity in Latvia at 10 meter altitude (Wind energy website 2011)

The use of wind energy in Latvia began in 1995, when the first wind energy facilities were established. In 2010, there were 47 wind energy facilities operating at 27MW, which represents 0.6 % of total electrical power consumed (Barons 2008).

Although the use of wind turbines for generating electric energy in Latvia still is under developed, the role of this renewable energy resource in Latvia´s energy balance is becoming more significant. In 2010 the volume of used onshore generated wind energy reached 1.8 %, and it is anticipated that by 2020 it will amount up to 11 % of the total of renewable energy (Ministry of Economics of the Republic of Latvia 2010) (see Figure 2).

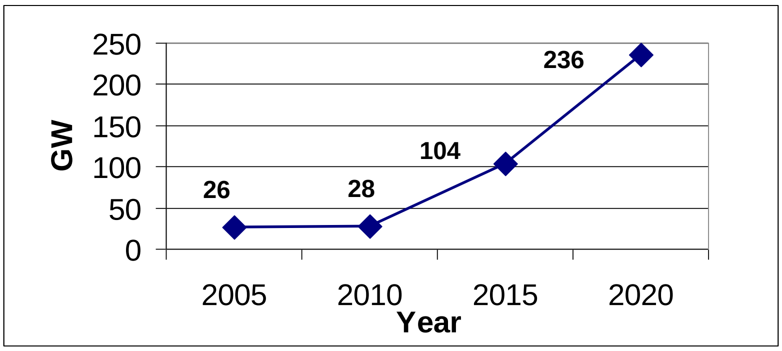


**Figure 2:** The use of onshore wind energy in Latvia, Years 2005-2020
(Author, using the data of the Ministry of Economics of the Republic of Latvia 2010)

These wind energy production plans, the decrease of different administrative, infrastructural, financial and social obstacles, the attachment of wind energy´s purchase price to the tariff of natural gas, as well as the high mandatory purchase prices of wind energy have created a favorable situation for wind park development in Latvia (Barons 2008).

## METHODS

### The methodology of the research study

The study consists of research of Liepāja region´s territory in the context of wind turbines and wind parks development. Liepāja region as a research territory was chosen due to the following reasons: the meteorological and orographic situation, the existence of wind parks and their development perspectives, complains and constitutional law-suits brought to the courts by local residents. The case study includes on the site inspection of research territory at the parishes of Grobiņa, Medze, Dunika and Vērgale (hereafter in the text when speaking about the parishes, only the toponym will be used), studies of literature, documents and legislation, as well as structured interviews. The interviews were held with the representatives of local administration and with inhabitants of Grobiņa and Vērgale that are living within 500 m of the wind turbines. The selection of interviews includes 50 % of Grobiņa residents and 100 % of those of Vērgale. The interviews included questions about respondents' point of view regarding the acoustic discomfort created by the wind turbine noise, residents' awareness of the possible negative effects of wind energy facilities, as well as the population's activity in processes of territorial planning.

### Location of the research

Within the framework of the case study the operating wind parks in Grobiņa and Vērgale and the planned ones in Medze and Dunika were inspected. The technical characteristics for them are shown in Table 1.

**Table 1:** Technical characteristics of the wind parks (Author, using the data from Environment State Bureau website 2011; Constitutional Court of the Republic of Latvia 2011a, b)

| Territory | Year of construction | Number of wind turbines | Power of the wind park (MW) | Height of the turbines (m) |
|---|---|---|---|---|
| Grobiņa | 2002 | 33 | 20 | 77 |
| Vērgale | 2007 | 3 | 2,5 | 30,50 and 80 |
| Medze | *Scheduled for 2011* | 4 | 1 | 51 |
| Dunika | *Scheduled for 2013* | 41 | 117 | 148 |

All wind turbines are located in areas of detached houses and recreation, where the construction of wind turbines is permitted. The closest houses in Grobiņa, Vērgale and Medze are located at a distance of 250-300 m from the wind turbines, but in Dunika – at a distance of 500 m. The wind park of Grobiņa is located in an open field where circa 30 residential houses are situated. In Vērgale, however, the wind turbines are located at the edge of a forest and there are 2 residential buildings near.

## RESULTS

The data gathered in the investigation are examined and analyzed in several sections: the noise level created by the wind turbines and its impacts, the information delivered to the society, the involvement of the local population, the territorial planning process as well as monitoring.

### Levels of noise, their influence and the attitude of local residents towards the wind parks

The data obtained from the interviews indicates that the majority of respondents living in near proximity to the wind parks perceived the sounds created by the wind turbines as undisturbing. In the meantime, part of the residents point out the impacts on health caused by the noise, acoustic discomfort generated by the wind turbines, the limitations of outdoor recreation caused by vibrations, as well as express their concerns regarding wind turbine impacts on health. People who express negative attitude or are drawing the attention to health hazards are the owners of properties near the land where the wind turbine is located, consequently they obtain no direct profit from the development of wind park. The results of the interviews are summarized in Table 2.

**Table 2:** The responses of respondents about the noise of active wind turbines (Author 2011)

<table>
<tr><td>Criteria</td><td colspan="2">Grobiņa</td><td colspan="2">Vērgale</td></tr>
<tr><td>Level of noise</td><td colspan="2">Within the level permitted by the regulations</td><td colspan="2">Within the level permitted by the regulations</td></tr>
<tr><td rowspan="3">Percentage of inhabitants that felt the disturbance</td><td rowspan="3">8 %</td><td>Felt sleep disorders, agitations, headaches</td><td rowspan="3">0 %</td><td rowspan="3">-</td></tr>
<tr><td>Had objected to the construction of wind turbines</td></tr>
<tr><td>The results of visual inspection revealed the poor technical condition of residential buildings of these respondents</td></tr>
<tr><td rowspan="2">Percentage of residents that were insusceptible to direct disturbance from the noise, but still experienced negative impact</td><td>3 %</td><td>Felt the transmission of vibration on earth´s surface</td><td rowspan="2">50 %</td><td rowspan="2">Disliked the humming sound from wind turbine at 2 MW</td></tr>
<tr><td>6 %</td><td>Considered that the low frequency sounds affect health. All the responders objected to the construction of wind park</td></tr>
<tr><td>Percentage of residents that noted other impacts on health</td><td>3 %</td><td>Concerned about the morbidity of cancer and the rise of blood pressure</td><td>0 %</td><td>-</td></tr>
</table>

In the meantime, the negative attitude towards wind turbines of large part of the population inhabiting the territory of existing or planned wind parks is based on possible decrease of their quality of life. It is proved by petitions against the construction of wind parks, addressed to the municipalities, signed by 55 inhabitants of Medze (pop. 1,558) and 182 of Dunika (pop. 749), that are based on their concerns about impacts of wind turbines on human health, inclusive about the acoustic discomfort (Constitutional Court of the Republic of Latvia 2011a, b). Although the foreseen level of noise in these parishes is lower than the maximum permitted, the worries of residents of Dunika are increased by the fact, that the results of simulation anticipate level of noise of 39 dBA at the nearest dwelling that is by 1 dBA lower than the permissible level of environmental noise at night in this building zone (Constitutional Court of the Republic of Latvia 2011b).

In addition to submitting the above mentioned petitions, in year 2010 with the support of non-governmental organizations residents of Medze and Dunika have brought a petition to the Constitutional Court (Constitutional Court of the Republic of Latvia 2011a, b) to litigate the territorial planning, that provides the construction of the wind turbines near the dwellings of the litigators and the incorporation of their properties in the territorial zoning of wind park, thus infringing property rights of these residents and their rights to live in congenial environment.

In both cases the Constitutional Court ruled that in the territorial planning plaintiffs´ ownership limitations have been foreseen, but that has been done with a legitimate purpose: to ensure the welfare of the society. The Constitutional Court pointed out that defining the planned use of the territory as that of a wind park, is hazardless to the health and life quality of the residents, because regardless of the solution chosen in the territorial plan, the operation of the wind park will be permissible, only in the case that the environmental noise is under the levels stipulated by the law.

## Conditions of securing the quality of information

The inhabitants of Grobiņa and Vērgale consider that in overall the information they received from the municipalities, the enterpriser and non-governmental organizations, has been of limited quantity and quality, in consequence they lack certainty that the wind turbines are harmless. All the respondents recognize that they would have wished and still desire to receive extensive and reliable information about the possible impacts of the wind park. For further information, see Table 3.

**Table 3:** The answers of the respondents about the quality and volume of available information (Author 2011)

<table>
<tr><th>Criteria</th><th>Grobiņa</th><th>Vērgale</th></tr>
<tr><td rowspan="3">Information about the wind park and the process of its planning and construction</td><td>100 % of the owners of the land where the construction of the wind turbines were planned consider that they have received the information on time and in a sufficient amount.</td><td>50 % of all inhabitants consider to have lacked sufficient information</td></tr>
<tr><td>55 % of inhabitants that live near the wind turbines, which stand on land owned by others, lacked sufficient information on any stage of the development of the wind park</td><td rowspan="2">50 % of all inhabitants were invited to public discussion, but failed to attend. They lacked access to additional information.</td></tr>
<tr><td>8 % of inhabitants that live near the wind turbines, which stand as planned on land owned by others, learned about the construction of the wind park only when the construction works begun.</td></tr>
<tr><td>Information about the level of noise created by the wind turbines</td><td>All inhabitants consider they lacked information about the level of noise</td><td>All inhabitants consider they lacked information about the level of noise</td></tr>
</table>

People, who own properties neighboring lands on which the wind turbines are located, point out that their opinion before the construction of the wind park was unsolicited and a survey to determine public opinion should have been conducted. It also should have been ensured that the people inhabiting in the vicinity of the wind turbines had had direct information about the municipality´s plans.

## Conditions of ensuring the public activity

The research shows that in the process of elaboration of the territorial plan and detail planning only a small part of Grobiņa respondents and none of Vērgale respondents participated. Both Vērgale and Grobiņa residents were inactive in the processes of planning of the wind parks, due to the belief that public activities have no impact on the result. The residents of Grobiņa indicate that the low level of their participation is related to lack of information about the process of public discussion. For further information, see Table 4.

Meanwhile the inhabitants of Dunika draw out attention to a formal process of public discussion of the territorial plan and the detail planning, where the objections of the public were discarded and no reasonable arguments given why the public opinion has been dismissed. The local population believes that it was insufficiently informed about the public discussion and the municipality failed to respond to their questions and deal with their petitions (Constitutional Court of the Republic of Latvia 2011b).

**Table 4:** Respondents' answers about the processes of public involvement (Author 2011)

<table>
<tr><th>Criteria</th><th>Grobiņa</th><th>Vērgale</th></tr>
<tr><td rowspan="4">Percentage of residents that have participated in the process of elaboration of territorial planning and detail planning</td><td>8 % of all inhabitants</td><td rowspan="4">0 % of all inhabitants that live in neighborhood of land where the wind turbines are constructed</td></tr>
<tr><td>100 % of owners of the lands where the wind turbines are constructed</td></tr>
<tr><td>3 % of inhabitants that live near the wind turbines, which stand on land owned by others</td></tr>
<tr><td>25 % of respondents that initially have been against the construction of wind park</td></tr>
</table>

## Conditions of monitoring

The legislation does not stipulate the need to conduct monitoring of levels of environmental noise. Residents have doubts about the stimulated level of noise, considering that these actions are performed by the developers of the wind parks; neither have the belief that these levels are observed.

## Conditions of elaboration of territorial planning

The inhabitants of Dunika have indicated to procedural violations in the elaboration of territorial plan, when the area of the wind park was defined after the public discussion and after the documents were send out for adjustments to the controlling institutions. After adjudicating this case, the Constitutional Court (Constitutional Court of the Republic of Latvia 2011b) has concluded that municipality of Dunika has committed procedural violations, and as a result the strategic evaluation procedure of impact on the environment was left out.

## DISCUSSION

The analysis of results outlined several problematic matters:

- Local population considers the wind parks to be significant sources of environmental noise, which can have an impact on quality of their life. The residents experience the acoustic discomfort, the health and social behavior disorders, and they point out to other possible impacts that lack scientific proof. That demonstrates the public´s concerns about possible impacts of wind parks on their health;
- The acoustic discomfort is higher from big wind turbines, groups of wind turbines and in places with higher population density, but considered layout of the wind turbines could diminish negative reaction of the population;

- The wind parks are designed to operate close to permissible levels of noise, thus increasing the society´s concerns about their possible impacts on health. Similarly it should be indicated, that by the law the level of environmental noise is measured as $L_{day,}$ $L_{evening}$ and $L_{night}$, considering all the periods during a year, thus indicating a general level of acoustic discomfort, but fails to do so with short-term, accidental exceeds of noise level, which also can cause changes in social behavior;
- Wind parks are developed without real evaluation of the local situation and analysis of public opinion, as well as without sufficient and good quality information about wind parks ensured to the public. These factors along with procedural violations in the process of territory planning have contributed to concerns of the local population about the insufficient evaluation of impacts of wind park development, which prevent the acceptance of development of wind energy facilities as a harmless process of municipality´s development and creates protests from the residents;
- The discomfort, health disorders and changes in the social behavior generated by the wind parks affects more those people, whose dwellings are of poor technical condition, residents that have no wind turbines located on their properties but on those of their neighbors. Negative attitude is also expressed by those residents that gain no benefits from construction of wind turbines or those who believe that the promises of the developers of wind park have failed to come true.
- The residents failed to initiate any activities related to wind parks due to the belief that the municipality had no interest in their opinion and they lack power over processes of development of the municipality. On the occasions when mediators are involved in wind park processes and similar activities take place in other territories, the residents take more active participation in the processes of wind park planning;
- The residents desire to receive reliable and scientific information about the wind parks, their impact on the health and actual noise level, that would be monitored regularly, before and after the construction of the wind parks;
- The study shows that the solution of issues related to the management of environmental noise generated by the wind turbines in the municipalities should be developed in five main directions, using normative, institutional, communication and planning instruments.

**1. Analysis of local situation and public opinion.** Before the development of wind park it is necessary to conduct surveys in order to learn public opinion, to obtain information about the unclear matters and issues of public interest, to identify the potential level of opposition, to prepare a full public awareness and participation program, as well as to stimulate the creation of reflexive connection. Such activities would help diminish the society´s concerns regarding an unfair threat to their environment and health.

When assessing the changes in life quality caused by the wind-turbine generated noise, not only the securing of law permitted outdoor noise level should be taken into account, but also the technical condition of the dwellings and the possibility of securing an appropriate indoor noise level, the excess of which can be the reason for sleep disturbance. Municipalities in the territorial planning and the environmental institutions in their licenses should stipulate the demand to simulate and measure indoor noise level, and in case of excess, order as the wind park developer´s duty to ensure anti-noise measures.

**2. Ensuring the information.** The society at all stages of wind park development should be informed about wind parks´ technical parameters, their interpretation, as well as specific impacts to expect. The given information should be verified, reliable and as objective as possible, and at the same time it should be comprehensible for any audience. The accessibility of the information should be also insured in mass media and public spaces and via individual communication with those residents on whose land the equipment is to be constructed or those who live in close proximity.

**3. Ensuring the public activity.** Municipalities should avoid formal involvement of the society and should decide about addition distribution of the information. The municipality should ensure the distribution of the announcements in public spaces, and should determine them based on analysis of everyday's movements of the population as well as by evaluating the possibilities of residents of location where a particular project is being developed, to get acquainted with the information. During the process of public discussion the municipality should ensure the participation of independent experts, in order to give a justified response to public questions and to decide about implementing the public suggestions.

**4. Monitoring.** Monitoring of environmental noise should be performed at all stages of development of wind parks, and the gathered information should be offered to the society, thus ensuring a permanent sense of acoustic security for public. In addition, the legislation or the permissions granted by the environmental institutions should stipulate the obligation of the contractor to conduct a regular monitoring of indoors and outdoors noise level.

**5. Territorial planning**. Municipalities should ensure that the process of territorial planning is being realized in compliance with laws and regulations. Procedural violations in the process of territorial planning increase suspicions and opposition towards the planned activities in the society.

This approach could be used for other projects that anticipate issues with populations´ subjective perception of noise, because it stimulates a more favorable attitude in the society and helps to prevent ungrounded complaints.

## CONCLUSIONS

1. The society perceives the environmental noise generated by the wind parks as an important factor that influences on the quality of the life, but about which in general they lack information. Because of the shortage of the information, with concerns about the evaluation of the impacts of wind parks and bearing negative attitude towards the project, residents consider noise to be a bigger threat than is has been proven by the simulation data and scientific studies and protest against the planned type of municipality's development.

2. Acoustic discomfort is higher when sound is generated by more powerful wind turbines, groups of them and in places with higher population density. The subjective level of discomfort and the level of impacts on health depend on the fact if the turbine is located on the land of the respondent, if the wind turbine gives not only a general but also a private gain, and on the technical condition of the dwellings.

3. In order to diminish the negative attitude in the society and to promote the acceptance of wind parks as a territory acoustically safe for the health and life quality, by using the normative, institutional, communicational and planning instruments various actions should be implemented: 1) a territorial planning should be conducted in compliance with the legal procedures; 2) a detailed analysis of the situation and public opinion should be carried out; 3) based on the results of the later, the society should be sufficiently informed; 4) the public should be genuinely involved and reflexive connection should be ensured; 5) regular noise monitoring indoors and outdoors should be conducted and, if necessary, anti-noise measures should be applied.

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# Residential development near industrial noise emitters

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ABSTRACT

The Noise Policy Statement for England (NPSE) utilizes two established concepts from toxicology. They are NOEL – No Observed Effect Level and LOAEL – Lowest Observed Adverse Effect Level. The NPSE extends these to the concept of a SOAEL – Significant Observed Adverse Effect Level, the level above which significant adverse effects occur. One aim of the NPSE concerns the situation between LOAEL and SOAEL. It requires that all reasonable steps be taken to mitigate and minimize adverse effects on health and quality of life while also taking into account the guiding principles of sustainable development. This is consistent with consideration of Best Available Techniques (BAT) or appropriate measures under the EU's Industrial Emissions Directive (IED) and the UK's Environmental Permitting Regulations (EPR). Significantly, this would mean that any time noise levels could be above LOAEL values operators of regulated industry will need to demonstrate what noise mitigation has been considered, what mitigation has or will be adopted, a cost benefit demonstration as to why other measures are not being implemented and an explanation why emissions may be above acceptable levels on nearby land strategically designated for potential noise sensitive development. Where noise-related conditions have not been specifically written into a Permit, the Operator is still obliged to use BAT to implement and maintain appropriate preventative measures against noise related annoyance. This is often referred to as "residual BAT". This paper will discuss residual BAT and land use changes resulting in noise sensitive developments moving into the vicinity of EPR/IED authorized operations. This work is likely to be of interest to consultants, planners and policy makers involved in the control of environmental impacts of industrial activities.

## INTRODUCTION

### Legislative context

The key concerns regarding noise sensitive development near existing industrial land uses are:

- The occupiers of the new noise sensitive development may be subject to unacceptable noise.
- The existing industrial operation may be become subject to complaints from occupiers of the new noise sensitive development.

In the latter case, either common law or statutory nuisance, legal action be required to expend resources on implementing noise mitigation and management measures.

Control over the emission of noise from many industrial sites is exercised in the England by the Environment Agency via the Environmental Permitting regulations; whilst control over the emission of noise from an existing industrial site on any proposed nearby new noise sensitive is exercised by the local planning authority under the Town and Country planning regime.

## Noise Policy Statement for England (NPSE)

An overarching policy statement for noise in England was published by the UK Government Department responsible for noise, Defra, in 2010, in its introduction this policy states:

*"The Government is committed to sustainable development and Defra plays an important role in this by working to secure a healthy environment in which we and future generations can prosper. One aspect of meeting these objectives is the need to manage noise for which Defra has the overall responsibility in England."*

The NPSE goes onto describe its long term vision as being to:

*"Promote good health and a good quality of life through the effective management of noise within the context of Government policy on sustainable development."*

## Aims of the NPSE

This long term vision is supported by the following aims: Through the effective management and control of environmental, neighbor and neighborhood noise within the context of Government policy on sustainable development:

- avoid significant adverse impacts on health and quality of life;
- mitigate and minimize adverse impacts on health and quality of life; and
- where possible, contribute to the improvement of health and quality of life.

The NPSE goes onto to provide useful advice on interpretation of its aims, including at paragraph 2.18 where it states:

*"There is a need to integrate consideration of the economic and social benefit of the activity or policy under examination with proper consideration of the adverse environmental effects, including the impact of noise on health and quality of life. This should avoid noise being treated in isolation in any particular situation, i.e. not focusing solely on the noise impact without taking into account other related factors."*

The NPSE therefore strongly influences how the EPR/IED requirements are interpreted and applied.

ENVIRONMENTAL PERMITTING REGULATIONS (ENGLAND AND WALES) 2010

## Best Available Techniques (BAT)

In England and Wales the Environmental Permitting Regulations (England and Wales) 2010 require installations to be operated in such a way that "*all the appropriate preventative measures are taken against pollution, in particular through the application of BAT*".

The definition of pollution includes *"emissions which may be harmful to human health or the quality of the environment, cause offence to any human senses or impair or interfere with amenities and other legitimate uses of the environment"*. BAT is therefore likely to be similar, in practice, to the requirements of the long established Statutory Nuisance legislation, which requires the use of "best practicable means" to prevent or minimize noise nuisance.

## Reasonable cause for annoyance

In the case of noise, *"offence to any human senses"* may be judged by the likelihood of annoyance during the day or sleep disturbance at night. However, a lack of complaints should not necessarily imply the absence of a noise problem and in some cases it may be possible, and desirable, to reduce noise emissions still further at reasonable cost and this may therefore be BAT for noise emissions in some circumstances. Consequently, one of the aims of BAT should be to ensure that noise does not cause reasonable cause for annoyance to persons beyond the installation boundary.

## Balance of costs and benefits

BAT will be installation–specific and, in determining what constitutes BAT, a number of factors will need to be taken into consideration. The cost of applying a particular technique will need to be balanced against the increased benefit to the environment. Where an environment is particularly noise sensitive, the balance of costs and benefits will probably tip towards the need for additional cost, as the environmental advantages would justify the increased cost. In this case, the Operator may have to go beyond the standard that would constitute BAT in a less sensitive environment.

ASSESSMENT METHODS

## BS 4142 – Method of rating industrial noise in mixed residential and industrial locations

In the case of noise, "*offence to any human senses*" may be judged by the likelihood of complaints, which is conventionally assessed in the UK using the methodology of BS 4142 (1997). BS 4142 has been in use in various versions since the 1960's. A report by the National Physics Laboratory concluded that BS 4142 worked well in 80 % of cases; but it was sometimes used inappropriately and this contributed to a significant proportion of the cases where it was not as effective.

However, in the context of residual BAT the use of BS 4142 has the specific drawback that it is an external based assessment of the likelihood of complaints from persons residing in a dwelling; and therefore normally cannot be altered by mitigation incorporated into the noise sensitive scheme; although such mitigation can provide adequate protection and acceptable noise conditions internally and externally to the scheme.

Consequently, by solely using the external based methodology of BS 4142 to assess the potential impact of existing industrial noise on proposed new noise sensitive development; the only means of mitigating adverse impacts is to use distance separation. This leads to inefficient land use planning, and an element of injustice, as the noise generator is effectively sterilizing neighboring land for nose sensitive development, at the cost of the neighboring land owner. Whereas it is possible that the noise generator could use BAT to reduce noise emissions; and the nose sensitive development could incorporate mitigation by way of the scheme layout, orientation and building form so that even though any residual adverse BS 4142 assessment may not change; acceptable noise conditions can be achieved

ANNOYANCE

## Establishing design limits

The task in hand is to establish reasonable design limits for noise sensitive developments near industrial sources and threshold criteria for implementation of mitigation. Working on the basis of ensuring the equivalent of the *"avoidance of serious community annoyance is achieved"*, i.e. 55 dBA or below, an understanding of the possible annoyance response relationship to general community noise and to the specific industrial type noise in question is required.

Residual BAT for the most part concerns persons moving to an established noise source. Consequently, there is no need to take into account any synergistic influence that a change in noise conditions may have in causing a stronger adverse response than would be anticipated solely from looking at community response rates to steady state noise conditions.

Recent research reinforces that generally the A-weighted decibel provides a reasonably good indicator for predicting community annoyance from industrial noise; except where the noise contains a dominant low frequency component. The threshold of the onset of moderate annoyance for a significant majority of persons for steady-state, constant noise is around the continuous equivalent sound pressure level of 50 dBA. A few people are seriously annoyed during the day time at noise levels below around 55 dBA. With regard to industrial noise a comprehensive study in the UK concluded that "*in general there is no strong evidence that industrial noise produces higher annoyance response than transportation noise*". However, it is clear that any type of noise containing distinctive acoustic features such as tonality or impulsive elements may be more disturbing than another noise of similar level but without such features.

## Objective assessment of noise impacts

In general, noise can act as a distracting stimulus and may also affect the psycho-physiological state of the individual. A novel event, such as the start of an unfamiliar noise will cause distraction and interfere with many kinds of tasks. Noise annoyance may be defined as a feeling of displeasure evoked by a noise. Annoyance is affected by:

i. the equivalent sound pressure level,
ii. the highest sound pressure level of a noise event,
iii. the number of such events, and
iv. the time of the day.

The annoyance due to a given noise source is perceived very differently from person to person. It is also dependent upon many non-acoustic factors such as the prominence of the source, its importance to the listener's economy, and his or her personal opinion of the source.

## Alternatives to BS 4142

The Standard BS 7445-2 (1991), ISO 1996-2 (1987) states that the Rating Level has to be determined over reference time intervals related to the characteristics of the source(s) and receiver(s). The Rating Level defined in ISO 1996 – 2 is a measure of the noise exposure corrected for factors known to increase annoyance. The basic parameter is the A-weighted equivalent continuous sound pressure level or $L_{Aeq}$. The formula for the Rating Level is (in general terms):

$$L_R = L_{Aeq} + K_I + K_T + K_R + K_S$$

where:

$K_I$ is a penalty for impulses

$K_T$ is a penalty for tone and information content

$K_R$ is a penalty for time of day

$K_S$ is a penalty (positive or negative) for certain sources and situations e.g. low frequency dominated noise

## ISO 1996 Corrections used in other countries

The reference time periods vary 5 minutes at night to 1 hour during the day, although a 15 minute period can be preferred overall by some decision makers. The penalty for tones varies between 0 dB (no penalty) and 6 dB. Some countries use a single penalty value of 5 dB, while other countries use two or more steps. In most cases, the presence of tones is determined subjectively, but objective methods are increasingly used. These methods are based on 1/3-octave or FFT (Fast Fourier Transform) analysis.

## Corrections for impulsive noises

It is not possible to lay down definite criteria for impulsive sound, but it has been suggested in research that existing noise sources can be assigned to three different categories of "impulsive noise" (see Table 1).

1. ordinary impulsive sound,
2. highly impulsive sound, and
3. high-energy impulsive sound.

The maximum penalty for impulsiveness can vary up to 7 dB between countries, and both subjective and objective methods are used. The objective methods are based on the difference between a fast reacting and a slower reacting measurement parameter (for example, between Impulse and Fast A-weighted levels) or it can be based on the type of source, using a list enumerating noise sources (such as hammering, explosives, etc.).

Impulsive noise may be more annoying than non-impulsive noise where each of them produces the same equivalent level $L_{eq}$. Impulsive noise is rated by making "adjustments" to the relevant $L_{eq}$ of the impulsive noise. There is a very wide range of possible adjustments for impulsive noise, from 2 dB up to 15 dB, depending on the circumstances. Regulations in European Countries lay down various adjustments (depending on the tradition in the countries concerned). Table 2 shows the adjustments made for impulsive noise in some European States.

Given the above it is not unreasonable to assume the single 5 dBA correction for tonality (although this could be further justified using a 1/3 octave band analysis of the data) and an impulsiveness correction of 5 dBA. In the UK, BS 4142 uses only one correction of 5 dBA to cover all acoustic features.

**Table 1:** Adjustments made for impulsive noise in some European States

| Differences in tonal and impulse corrections for different countries | | |
|---|---|---|
| **Country** | **KT in dBA** | **KI in dBA** |
| Austria | 3 or 6 | 3 if $L_{A,I,max}$-$L_{A,F,max}$ <2 dB<br>5 if $L_{A,I,max}$-$L_{A,F,max}$ >2 dB |
| Belgium; Flemish | 5 or 2<br>music : 5 | $L_{A,i,max}$ <2 s<br>difference $L_{A,I,max}$ and $L_{Aeq}$ :<br><20 dB day, <15 dB evening and night |
| Belgium, Brussels | 2 to 6 | $L_{A,I,eq}$-$L_{Aeq}$ |
| Belgium, Walloon | 2 to 6 | 5 if $L_{A,I,max}$-$L_{A,S,max}$ >5 dB |
| Denmark | 5 | 5 |
| France | 5 | 3 or 5 or 10 depending on duration and $L_{A,F,max}$-$L_{Aeq}$ |
| Germany | 3 or 6 | $L_{A,I,eq}$-$L_{Aeq}$<br>or $L_{A,FT,eq}$-$L_{Aeq}$ |
| UK (only KT or KI) | 5 | 5 |
| Italy | 3 | 3 if $L_{A,i,max}$-$L_{A,F,max}$ >6 dB , and<br>$L_{A,F,max}$ <1 s, and N>10 in daytime or N >2 in night time. |
| Netherlands | 5 (audible tones) | 5 (audible impulses) |

SLEEP DISTURBANCE

### World Health Community Noise Guidelines

For night-time, noise sources the World Health Community Noise Guidelines (WHO 1999) recommend a night-time (23.00-07.00) noise level of 30 dB $L_{Aeq,8h}$ inside bedrooms (for a reasonably steady noise source) and on a sleep disturbance basis the WHO guidelines state in Section 3.3 that:

*"For a good sleep, it is believed that indoor sound pressure levels should not exceed approximately 45 dB $L_{Amax}$ more than 10-15 times per night……"*

In 2003, the WHO Regional Office for Europe set up a working group of experts to provide scientific advice for the development of Night Noise Guidelines (NNGs) for future legislation and policy action in the area of control and surveillance of night noise exposure.

### WHO Night Noise Guidelines for Europe (NNGS)

Since the publication of the initial NNGS in 2007 which were based on no observed adverse effects level (NOAEL), various comments were received regarding the achievability of the guideline values. In response the WHO in consultation with international experts and stakeholders including the EU, agreed that the guidelines should be based on the lowest observed adverse effects level (LOAEL) rather than the NOAELs. In addition, an interim target was also introduced as a feasibility-based guideline. These findings were published in 2009 and it is this version of the Night Noise Guidelines for Europe (NNGS) that are current. The latest NNGs do not supplant the existing WHO Community Noise Guidelines (WHO 1999) and are described in the document as complementing them.

The NNGs specify use of the cumulative annual metric $L_{night}$ – the annual average equivalent sound level between 23:00 and 07:00 — to protect against sleep disturbance. There are two recommended values as follows:

- Night noise guideline (NNG) $L_{night,outside}$ = 40 dBA
- Interim target (IT) $L_{night,outside}$ = 55 dBA

### Internal noise conditions at night

The NNGs are widely exceeded across the UK and Europe. Furthermore, it is clear that use of the ultimate NNG target will result in costs to both individuals and society overall that are substantial e.g. cessation of virtually all public and private transport and severe curtailment of much economically and socially useful activity at night; and exclusion of large swathes of land from noise sensitive development. Currently, neither the UK government nor the devolved administrations have incorporated the WHO Night Noise Guidelines into policy or indicated that they are likely to do so.

Indeed, given that the Noise Policy Statement for England at paragraphs 2.20 and 2.21 reinforces that it seeks to avoid "*significant adverse impacts*" and distinguishes these from the more stringent "*Lowest Observed Adverse Effect Levels*" used to set the WHO's ultimate night-time noise target; it is clear that noise policy in England does not promote or otherwise sanction the ultimate WHO night noise target of $L_{night,outside}$ 40 dBA as an overall policy objective. Instead as a more sustainable control, where appropriate, it is expected that internal noise conditions at night can be managed by using noise sensitive scheme layout, orientation and building form to achieve acceptable internal conditions; albeit subject to suitable provision for ventilation. The noise levels to be aimed for internally are the guideline values for within bedrooms from the earlier WHO Community Noise document.

### Free-field noise conditions at night

Consequently if the use of BAT by an operator means the noise levels from an EPR/IED installation does not exceed 45 dBA $L_{Aeq,t}$ or 60 dBA $L_{Amax}$ under free-field conditions; noise would not be a material consideration for the noise sensitive development of the affected land.

On the other hand, if despite the application of BAT by the operator the noise level from an EPR/IED installation does exceed 45 dB $L_{Aeq,t}$ or 60 dB $L_{Amax}$ under free-field conditions; noise would be a material consideration for the noise sensitive development of the affected land; and any scheme would need to incorporate measures to reduce predicted internal noise levels in bedrooms to below 30 dB $L_{Aeq,t}$ or 45 dB $L_{Amax}$ as appropriate.

## CONCLUDING REMARKS

Although conventionally used in the UK to assess industrial noise, BS 4142 is inappropriate for the assessment of existing industrial noise on proposed new noise developments. Although the new scheme can incorporate mitigation to achieve acceptable noise conditions, the BS 4142 rating level may not change. Instead it is considered appropriate to rely on absolute noise level targets appropriately adjusted for acoustic features as recommended in ISO 1996/BS 7445. Appropriate design standards for industrial noise can be based on WHO Community Noise guideline levels suitably adapted for acoustic character as per ISO 1996/BS 7445.

In regard to annoyance, it is not unreasonable to assume the single 5 dB correction for tonality. This can be further justified using a 1/3 octave band analysis of the data. An impulsiveness correction of 5 dB could be justified by further integration of the gathered data. For tonal noise with impulsive elements, this then leads to a potential mitigation external design target of 55 dB - 10 dB = 45 dB $L_{Aeq,t}$.

With regard to sleep disturbance, the WHO NNGS are regarded as too restrictive and impracticable. Instead, for night-time noise sources, the World Health Community Noise Guidelines are preferred i.e. night-time (23.00-07.00) noise level of 30 dB $L_{Aeq,2300\ to\ 0700h}$ inside bedrooms (for a reasonably steady noise source) and indoor sound pressure levels should not exceed approximately 45 dB $L_{Amax}$ more than 10-15 times per night. Where the noise source is not steady, the time period t for the 30 dB $L_{Aeq,t}$ shall reflect the duration of the higher noise levels within the operational cycle.

A simple risk assessment can enable the relative risk to the industrial noise source and the occupiers of any new nearby noise sensitive development to be evaluated and appropriate measures to be enforced on either the noise emitter by the Environment Agency, on the new noise sensitive scheme; or both.

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# Contribution of genetic factors to noise-induced hearing loss

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## INTRODUCTION

It is widely accepted that noise-induced hearing loss (NIHL) is a complex disease which results from the interaction of genetic and environmental factors. Heritability might be responsible for up to 50 % of the hearing loss variability after exposure to noise.

The genetic basis of NIHL has been clearly demonstrated in animals. Mouse strains (C57BL/6J – B6) exhibiting age-related hearing loss (Ahl) were shown to be more susceptible to noise than other strains (Erway et al. 1996; Davis et al. 2001). Also, several knockout mice including SOD1-/- (Ohlemiller et al. 1999); GPX1-/- (Ohlemiller et al. 2000); PMCA2 -/- (Kozel et al. 2002) and CDH23+/- (Holme & Steel 2004) were shown to be more sensitive to noise than the wild-type littermates.

Over the last 10 years a great increase in association studies that were trying to identify the susceptibility genes for NIHL in humans was also observed. Tens and hundreds of Single Nucleotide Polymorphisms (SNPs) of different genes that are known to play a functional and morphological role in the inner ear were screened. SNPs are common point mutations in the genome (occurring every 100 – 300bp), and their genotyping is believed to be a successful tool in analysis of the genetic background of complex diseases, like NIHL. In such studies, disease susceptibility allele is expected to occur more often in susceptible group than in a resistant one.

## METHODS

The aim of this paper was to overview human association study results on gene polymorphisms in human populations exposed to noise and indicate the first potential susceptibility genes for NIHL. The review includes papers published over the last 10 years in English. Eleven most crucial human papers were identified by literature search of accessible medical and other databases (PubMed, Embase, Scopus, BioMed Central, Web of Science).

## RESULTS

So far, the most promising results were obtained for genes involved in the inner ear potassium ion recycling (van Laer et al. 2006; Pawelczyk et al. 2009) and heat shock protein genes (HSP70) (Yang et al. 2006; Konings et al. 2009a), because they were replicated in the independent populations, and were sufficient in size to yield high power for the detection of a causative allele. The other genes of interest are oxidative stress genes (Rabinowitz et al. 2002; Fortunato et al. 2004, Carlsson et al. 2005; Konings et al. 2007). Lately, the significance of genetic variation in NIHL development has been also shown for otocadherin 15 and myosin 14 genes (Konings et al. 2009b).

## Potassium-recycling genes

$K^+$ recycling is of great importance for the process of hearing. The ions are secreted into the endolymph by the stria vascularis, enter the hair cells through apical mechanosensitive $K^+$ channels and leave these cells via their basolateral membrane, then migrate through supporting cells and fibrocytes toward the stria vascularis using a network of gap junctions. $K^+$ recycling genes seem to be very good candidate genes for susceptibility to NIHL, what is supported by the fact that mutations in $K^+$ channel genes in the inner ear often lead to hearing loss. Mice deficient for *KCNE1*, *KCNQ1* or *SLC12A2* have collapsed endolymphatic spaces, while in humans several mutations in *KCNQ1* or *KCNE1* potassium channel subunits lead to pathological cardiac and auditory phenotypes.

A total of 10 genes putatively involved in potassium ions recycling in the inner ear were examined, namely five connexin genes: Cx26 (*GJB2*), Cx30 (*GJB6*), Cx30.3 (*GJB4*), Cx31 (*GJB3*) Cx32 (*GJB1*), four potassium channels or subunits (*KCNJ10*, *KCNQ4*, *KCNE1*, *KCNQ1*) and one Na+/2Cl-/K+ co-transporter in large populations of Swedish and Polish workers. Allele, genotype and haplotype frequencies were compared between noise-susceptible and resistant groups (103 susceptible and 114 noise-resistant workers selected from over 1200 subject database in Sweden, and 119 susceptible and 119 resistant workers selected from the subpopulation of over 3,000 subject database in Poland) (Carlsson et al. 2005; van Laer et al. 2006; Pawelczyk et al. 2009).

In the Swedish sample, significant differences were observed for 3 SNPs of *KCNE1*, one SNP for *KCNQ1*, and one SNP of *KCNQ4*, suggesting that these are first defined susceptibility genes for NIHL (Van Lear et al. 2006). In the Polish sample, which comprised substantially more SNPs (99 vs. 35 in the Swedish sample), a significant associations were found in 7 out of 10 genes (*KCNE1*, *KCNQ4*, *GJB1*, *GJB2*, *GJB4*, *KBNJ10*, *KCNQ1*) (Pawelczyk et al. 2009).

The most interesting results were obtained for *KCNE1* and *KCNQ4*, as the authors replicated associations for the same SNPs that were previously reported in a Swedish sample set (rs2070358 and Q455H, respectively). The direction of genetic trends for *KCNE1* was the same in both populations, but opposite for *KCNQ4*, questioning the replication for the latter gene. Since the analysis of the linkage disequilibrium (LD) pattern within the region of *KCNE1* demonstrated that rs2070358 and D85N were not in LD with each other, certainly *KCNE1* can be considered as NIHL susceptibility gene. In Polish sample set a significant association was also found for KCNQ1; however, in different SNPs than in the Swedish population. However, taking into account that different SNPs association in different populations but within the same gene, may be regarded as a replication, it seems likely that, in addition to *KCNE1*, also *KCNQ1* is truly a susceptibility gene for NIHL.

*KCNE1* and *KCNQ1* are functionally linked. *KCNE1* encodes a $K^+$-channel beta subunit. It requires coexpression of an alfa-subunit, usually *KCNQ1*, to generate a functional $K^+$ channel. KCNQ1/KCNBE1 channels are present at the marginal cell membrane of stria vascularis and play a major role in cardiac as well as inner ear function. *KCNE1* mutations cause long QT syndromes (the autosomal recessive Jervell and Lange-Nielsen syndrome or the autosomal dominant Romano Ward syndrome). It has been shown that in the inner ear, the presence of *KCNE1*-p.85N variant might lead to slightly higher $K^+$ concentrations, what would render the organ of Corti more sensitive to noise damage (van Laer et al. 2006).

### Hsp70 genes

Heat-shock proteins (HSPs) form a group of conserved proteins assisting in synthesis, folding, assembly and intracellular transport of many other proteins. HSPs are ubiquitously expressed in the body cells under physiological and pathological conditions. Their expression increases under stressful condition, including noise exposure. When first induced by exposure to moderate sound levels, they can protect the ear from excessive noise exposure. Three genes are responsible for HSPs synthesis, *HSP70-1*, *HSP70-2* and *HSP70-hom*. The genes are heat inducible, except the last one.

Variations in HSP70 genes were shown to be associated with susceptibility to NIHL and these results were replicated in three independent populations, Chinese, Swedish and Polish (Yang et al. 2006; Konings et al. 2009a). In Chinese population of 194 autoworkers, no statistically significant difference was shown in the genotype and allele distribution among 93 subjects who developed hearing loss comparing with 101 subjects without hearing deficit. However, assuming that SNP may not be sufficiently informative in complex disease, haplotype analysis was preformed. It showed that two haplotypes among six were significantly more frequent in the NIHL group vs. control. Using similar methodology and data analysis for the same gene polymorphisms, these findings were confirmed in the groups of 206 Swedish and 238 Polish workers (group selection has been described above). One SNP, rs2227956 in *HSP70-hom*, resulted in a significant association with NIHL in both European sample sets. Moreover, one haplotype (GAC) was also associated with NIHL in both these sample sets, and one other 9 (CGT) in Swedish population. Haplotype GAC showed protective effect in both samples, with twofold decreased odds of developing NIHL.

The comparison of putative haplotypes among Asian and European populations revealed that haplotypes significantly associated with NIHL in Chinese people (GGC and GGT) were infrequent or absent in the Swedish and Polish population. However, it does not exclude a true association of this gene polymorphisms with susceptibility to noise, and may be explained by the ethnic difference between the sample sets.

Several other studies suggested that *HSP70* polymorphisms can be associated with many other diseases, including Parkinson’s disease, Crohn disease or ischemic stroke, among others. HSP70 protein may also play a role in autoimmune inner ear disease.

### Oxidative stress genes

Oxidative stress plays a major role in the pathomechanisms of NIHL. A local prolonged release of free radicals (reactive oxygen and nitrogen species) after noise overexposure may result in cochlear epithelium damage, particularly if the antioxidant defense system is not efficient enough to neutralize them.

There are two groups of antioxidant enzymes that are active in the cochlea. The first group comprises enzymes involved in glutathione metabolism, including glutathione S-transferase (GST), glutathione peroxidase (GPX1), and glutathione reductase (GSR). GST classes comprise *GSTM1* and *GSTT1* genes which show great genetic variability in humans. Up to 50 % of the Caucasian population are null genotypes for

*GSTM1* gene, and 25-40 % of the Caucasian population are null genotypes for the GSMT1 gene. The second class of antioxidant enzymes includes the enzymes involved in the breakdown of superoxide anions and hydrogen peroxide (catalase – *CAT*, superoxide dismutase 1, Cu/Zn – *SOD1*, superoxide dismutase 2, mitochondrial – *SOD2*, serum paraoxonase/arylesterase 2 – *PON2*).

The results of the study on association between variations in oxidative stress genes snf susceptibility to NIHL are equivocal. First it was shown that *GSTM1* null individuals exposed to noise had lower amplitudes of high frequency otoacoustic emission comparing to individuals possessing the gene (Rabinowitz et al. 2002). Another study of a limited sample set suggested that *SOD2* and *PON2* gene polymorphisms may be associated with NIHL (Fortunato et al. 2004). However, all these associations might be incidental, due to insufficient power.

In much more comprehensive study performed in Swedish workers (103 susceptible to noise and 114 resistant to noise workers selected from over 1,200 subject database), none of seven oxidative stress genes, namely *GSTM1*, *GSTT1*, *CAT*, *SOD*, *GPX*, *GSR* and *GSTP1*, was shown to be a susceptibility gene for NIHL (Carlsson et al. 2005). However, the same authors have shown that the effect of smoking on susceptibility to NIHL is dependent on the presence of the *GSTM1* deletion, suggesting a substantial interaction of genes and environmental factors in NIHL development (Carlsson et al. 2005).

Similarly, association study in two large independent populations (Swedish and Polish, described above) indicates that the effect of Catalase (*CAT*) gene polymorphism on susceptibility to NIHL may only be detected when noise exposure level is taken into account (Konings et al. 2007). Moreover, the same genotype can have a differential effect on the susceptibility to NIHL, depending on the noise exposure level.

More recent studies support the role of oxidative stress gene polymorphisms in the development of NIHL. *SOD2* SNP in the mitochondrial targeting sequence was shown to be associated with noise-induced hearing loss in Chinese workers, and again this effect was enhanced by higher levels of noise exposure (Liu et al. 2010).

Also, double blind, crossover study in 53 male workers treated with N-Acetyl-cysteine support the hypothesis that individuals carrying all genotypes with *GSTT1* null, *GSTM1* null, and *GSTP1* Ile(105)/Ile(105) are more susceptible to NIHL (Lin et al. 2009). On the other hand, the ototoxicity of aminoglycosides, which seem to involve similar oxidative stress mechanisms, was shown to be independent of *GSTM1* and *GSTT1* gene polymorphisms (Palodetto et al. 2010).

## Other genes

Lately, an extended analysis of 644 SNPs in 53 candidate genes was performed in two independent (Swedish and Polish) populations. The positive associations were shown for two genes, one encoding protocadherin 15 (*PCDH15*), and the other encoding myosin 14 (*MYH14*) (Konings et al. 2009b). One SNP in *PCDH15* resulted in significant associations in both populations, and two SNPs in *MYH14* resulted in positive association in the Polish sample set and significant interaction with noise exposure level in the Swedish sample set.

Cadherins, namely cadherin 23 and protocadherin 15 are the molecules that form tip links between sensory hair cells of the cochlea, and are essential for the mechanoelectrical transduction (Sakaguchi et al. 2009). It was shown that mutation in *Cdh 23* disrupted stereocilia organization on hair cells leading to deafness and vestibular dysfunction in waltzer mice; the 753A variant of his gene was correlated with susceptibility to noise-induced hearing loss (Noben-Trauth et al. 2003). In humans, *PCDH15* and *CDH23* gene mutations are associated with both syndromic and non-syndromic hearing loss (DFNB23, Usher syndrome type 1F, and Usher syndrome type 1D, respectively).

*MYH14* encodes one of the proteins of the myosin superfamily. They are actin-dependent motor proteins regulating cochlear hair cells motility and polarity. Mutation in *MYH14* results in autosomal dominant hearing impairment in humans (DFNA4).

## CONCLUSIONS

Up to now, association studies on susceptibility genes for NIHL were performed based on candidate gene approach. It was shown that several gene polymorphisms are probably involved in determining susceptibility to NIHL. In establishing the role of some of them, searching for the interaction between gene variations and environmental factors is necessary. It mainly regards noise exposure, since the mechanisms of cochlear damage is straightly related to its level and time of exposure.

To confirm the role of the gene in the development of NIHL, the replication of the results in independent population sample sets is mandatory. But, taking into account the ethnic differences the replication at the level of gene, and not necessarily the polymorphism or haplotype, is satisfactory. Due to difficulties in replicating the results on one hand, and the development of high-throughput genotyping methods along with the growing databases of SNPs on the other one, a logical next step for research on genetics of NIHL is Whole Genome Association Studies. Genomewide Single-Nucletide-Polymorphism association studies are optimal approaches for determining whether major genetic association exist in diseases with high heritability like NIHL. The development of the methods allowing to genotype hundreds and thousands of SNPs in a single array will undoubtedly lead toward identification of new NIHL susceptibility genes.

Detection of genetic factors contributing to the development of noise-induced hearing loss will allow for a better understanding of NIHL pathophysiology and it will indicative direction for further analysis of this condition. Identification of susceptibility genes may lead to the development of genetic tests which would allow to personalize treatment – gene therapy is a possible approach, but also applying specific medications might be advisable. It can also be helpful in identifying the population at high risk along with allowing for better hearing protection in predisposed individuals.

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# Night noise and sleep in Spain

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## ABSTRACT

Around 48 % of the complaints presented before the administration in Spain are related to noise produced by leisure activities at nighttime. In this paper the situation of night noise in Spain during the last 20 years is analyzed. Noise levels and social surveys from 100 towns of different size (with populations between 6,000 and several millions) have been reviewed from 1989 until 2010. In practically all the measurement points close to places with leisure activities, night noise levels were well above the 55 dBA recommended by local and national authorities, which should lead to sleep problems. Different studies show that between 20-60 % of the population affected by night noise have difficulties in falling asleep, awakenings during the night, etc. The most disturbing noise source at night is people in the streets, followed by the music emitted by discos and pubs.

## INTRODUCTION

Night noise has become an increasingly important problem in Spain over the last 30 years. Several factors are involved in this process. First, the increase in night clubs, discos and bars in practically all the small, medium and large size towns, together with an increase in the number of people going out at night. Second, closing times were not enforced in most cases, making for an endless night that went right into the next morning. The night leisure industry has grown to become a powerful social agent lobbying for keeping their present status, even if they do not comply with local regulations. In the last years, another way of going out at night has become very popular in Spain, the gathering in the open air of thousands of people to drink and party. In the rural areas, there has been also an increase in the traditional dancing parties in the outside that take place during local festivities, with bands playing with powerful equipments, accompanied by the use of loud fireworks. All the open air activities used to be associated with warm weather and summer, but now they can take place during any time of the year, including nights of bad weather. Social tolerance has lead to the idea that this is something that cannot be fought with the present regulations, since people have the right to enjoy themselves without any restriction during the night time. This tolerance contrasts with the impact of these activities on the population: around 48 % of the complaints presented before the administration in Spain are related to noise produced by leisure activities at night time (Goyenechea & Ortiz 2010). Information about the social effect of night noise in Spain can be consulted in the website ("http://www.ruidos.org/").

In this paper the situation of outdoor night noise in Spain during the last 20 years is analyzed. First we shall review the acoustic data available. We shall differentiate between studies of a general type, in which there is no specification of any particular noise source; studies in which acoustic data from areas with night leisure activities are compared with data from areas for which the main noise source is traffic; and studies where data from noisy nights (generally weekend nights with numerous people going to discos and pubs) are compared to data from quiet nights (generally the rest of the weekend). Second, the impact of night noise on the population is analyzed. We shall review the opinions of the people about the most disturbing night noise sources and the problems caused by noise on sleep, namely difficulties in falling asleep and awakenings during the night.

## METHOD

We shall review the different strategies for analyzing night noise data.

### Noise measurements and indexes

There is a wide choice of strategies to characterize night noise and its impact on the population. In most cases the recommended 55 dBA value for $L_{Aeq}$ has been adopted by local regulations as the outdoors night noise limit. The duration of the measurements varies a great deal among studies, from 5 minutes to a whole night, or even several nights. The way to present the acoustic data can be roughly divided into two strategies: a) In studies where measurements took place in specific places (selected for having a particularly dominant noise source, such as night leisure activities or traffic), $L_{Aeq}$ or even $L_{Amax}$ are usually the choice indexes; b) In studies where measurement points were randomly selected (using grids, etc.) the percent of points with $L_{Aeq}$ values above 55 dBA are presented. The first approach allows us to know the noise levels affecting people. The second approach is sometimes turned into a percent of people or a percent of town surface, and different levels are added (like percents over different noise levels, etc.). The method used to calculate the percent of people affected is unclear.

### Social surveys

The methodologies used to assess the reaction of people are based on social surveys conducted in different ways. In some cases the interest is focused on which is the most disturbing source of night noise. The usual choices are music and people on the streets, but traffic should also be included, although it actually appears only in one study. Other studies try to find out the percent of people affected by night noise, although there is no specification of the way in which people are affected or disturbed. Only in a reduced set of studies the influence on sleep is considered, with data related to the difficulties in falling asleep or to awakenings during the night. Only in one study the percent of people receiving medical attention due to the problems caused by night noise is considered. The way people were selected for the social surveys is unclear in some cases, and the data produced is not easily comparable among all the studies.

## RESULTS

### Acoustic data (unspecified source)

Table 1 presents mean $L_{Aeq}$ levels and the percent of points surpassing 55 dBA in studies which were not focused on the effect of a particular noise source. Each study is identified by its initials and the year of publication. In one case data correspond to range variations (i.e. GA89; Romero et al. 1989); in other cases the standard deviation is included (CV98; Garrigues & Garcia 1998; AN01a; AN01b; Arriaga et al. 2001). The case AN01a corresponds to the review of data from 18 towns of more than 50,000 inhabitants, while AN01b corresponds to the review of data from 44 towns with a population between 20,000-50,000 inhabitants.

**Table 1:** $L_{Aeq}$ levels and the percent of points exceeding 55 dBA

| | GA89 | GA06 | EIB92 | CV98 | AN01a | AN01b | HU08 | VLL10 | LE08 |
|---|---|---|---|---|---|---|---|---|---|
| $L_{Aeq}$ (dB) | 67-70 | | | 60±8.6 | 60±1.7 | 60±2.4 | 58.5 | | |
| >55 dBA | | 60 % | 100 % | | 77.9 % | 80.5 % | 72.7 % | 14 % | 26 % |

## Acoustic data of specific sources (night leisure activities and traffic)

Table 2 presents the ranges of $L_{Aeq}$ and $L_{Amax}$ values encountered in two studies dealing with the differences between areas where the predominant noise source is related to night leisure activities and areas where the predominant source is traffic.

**Table 2:** $L_{Aeq}$ and $L_{Amax}$ values in areas where the predominant noise source is related to night leisure activities and areas where the predominant source is traffic

| | $L_{Aeq}$dBA | | $L_{AMax}$ dBA | |
|---|---|---|---|---|
| | Leisure | Traffic | Leisure | Traffic |
| VA96 | 53.1-62.8 | 67.5-71.7 | 72.6-77.3 | 85.1-96.4 |
| AV99 | 65.9 | 46.9-60.3 | | |

## Acoustic data from specific days of the week (noisy and quiet nights)

Table 3 presents data obtained in the same points considering two different periods during the week: one with leisure activities working at full capacity (generally weekends, but in some places, like university towns, starting Wednesday or Thursday); and one with those activities closed (generally Mondays or some other day of the week). We shall henceforth call the first one “noisy night” and the second one “quiet night”. The studies which were particularly focused on areas with night leisure activities are presented in boldface. The study VA94a presents average data from 8 small towns from Valencia together with 7 streets of the same city, while VA94b presents data only from those 7 streets (Gimenez et al. 1994). The study SC09 (Feijoo 2009) presents two different data in each box, the first one corresponding to data from an area with leisure activities but without traffic, and the second one corresponding to an area with both noise sources.

**Table 3:** $L_{Aeq}$ levels and the percent of points exceeding 55 dBA during noisy and quiet nights

| | $L_{Aeq}$dBA | | >55 dBA | |
|---|---|---|---|---|
| | Quiet night | Noisy night | Quiet night | Noisy night |
| **VA94a** | **60** | **76** | | |
| **VA94b** | **65** | **75** | | |
| **CO95** | | | **70 %** | **87 %** |
| **ALQ98** | **58-72** | **69-78.4** | | |
| MAD00 | | | 38.4 % | 86.4 % |
| VLL03 | | | 52 % | 85 % |
| BIL03 | | | 49 % | 56 % |
| CLE03 | | | 22 % | 31 % |
| **SC09** | **54±5 ; 60±2** | **62±5 ; 66±3** | | |
| **OR04** | **55.6** | **61.2** | | |

## Social surveys: effects on sleep

Table 4 shows the percent of people whose sleep was perturbed by night noise. This includes the percent of people having difficulties in falling asleep or being awoken during the night. Only in one study the percent of people receiving medical attention due to sleep problems caused by noise is considered. Again, the studies which were particularly focused on areas with night leisure activities are presented in boldface. The study VA96 (Guijarro et al. 1996) is divided in two parts: data obtained in a place with traffic as the predominant noise source (VA96a), and data obtained in a place packed with leisure activities. The study SC09 is divided in three parts, the first one (SC09a) corresponding to a general survey of people living in areas packed with night leisure activities; the second and third one corresponding to answers given by people living in the particular homes where noise measurements were performed, either during quiet or noisy nights (referring to their sleep problems during that specific night).

**Table 4:** Percent of people with their sleep affected by night noise, including difficulties in falling asleep, awakenings during the night and those that had to receive medical attention.

| | % Affected | % Difficulties | % Awakenings | % Medical Att. |
|---|---|---|---|---|
| GA89 | | | 28-36 % | |
| ZA91 | 50 % | | | |
| VA96a | | 33 % | 22 % | |
| **VA96b** | | **58 %** | **42 %** | |
| VLL03a | 21-46 % | 22-44 % | | |
| BIL07 | 13.9 % | 43.4 % | | |
| **SC09a** | | **85 %** | | **31.2 %** |
| SC09(Quiet) | | 0 % | 4 % | |
| **SC09(Noisy)** | | **40 %** | **56 %** | |

## Social surveys: opinions of the people about the noise source

Table 5 shows the percent of people that consider a particular night noise source to be the most disturbing at night. The studies which were particularly focused on areas with night leisure activities are presented in boldface.

**Table 5:** Percent of people that consider a particular night noise source to be the most disturbing

| | GA89 | ZA91 | **ALQ98** | **LE08** | CLE03 | **SCQ09** |
|---|---|---|---|---|---|---|
| Music | 32 % | 18 % | **12 %** | **11 %** | 20 % | **39 %** |
| People | | | **68 %** | **46.4 %** | | **55 %** |
| Traffic | | | | | | **6 %** |

## Evolution of the problem along the years

Despite all the studies carried out since 1989, in only one of them (concerning 18 towns of more than 50000 inhabitants, Arriaga et al. 2001) there is information about noise levels during different periods: during 1992-93, average $L_{night}$ was 60.2±2 dBA, and during the period 1995-98 it was 60±1.7 dBA. Data from every town in that study show a similar trend, with little variations in levels between both periods. In other places where studies were carried out along several years (i.e. Leon, between 2000 & 2008; Cepeda et al. 2008) the use of different methodologies in each one of them prevents us from following the evolution in either levels or in the response of people before noise.

## DISCUSSION

According to the acoustic data gathered over the years, night noise levels in Spain are usually above the 55 dBA recommended by local noise ordinances. Although it is not conclusive, the presence of night leisure activities means an increase in levels with respect to other areas, and certainly an increase in those same areas compared to nights with the activities closed. For these areas, an average increase between 4-15 dBA can be expected during noisy nights. It is difficult, though, to determine the percentage of people affected by those levels. The percent of measurement points with levels above 55 dBA ranges from 14 % to 100 % in studies with an unspecified noise source, while in places with night activities it ranges from 22 % to 70 % (quiet nights) and from 31 % to 87 % (noisy nights). There is an increase in the number of points with levels higher than 55 dBA during noisy nights, between 7 % and 48 %. This increase in noise levels affects not only the places with nightlife, but also other areas, probably through an increase in both traffic and in people walking in the streets going from one place to the other. Nevertheless, it is not easy to calculate the number of people affected using only the acoustic data, since the effect will depend on the floor where each dwelling is located, its situation with respect to the most exposed facade, the situation of the bedroom inside the house, the number of people inside, the acoustic insulation of the building, etc.

The sleep of between 14-50 % of the population of several cities (higher than 300,000 inhabitants) seems to be affected by night noise (unspecified source). In two of these cities the percent of people that have difficulties in falling asleep lies between 22-43 % (Guijarro et al. 1996; Martin et al. 2003). Data from a popular summer holiday resort show that 28 % of the population is awoken often or vey often by noise (Romero et al. 1989). The rest of the data comes from studies on the effect of nightlife activities and the percents given usually refer to people living in the specific area analyzed. Between 58-85 % of the people living in nightlife areas have difficulties in falling asleep during noisy nights, while in areas with traffic as the main source the percentage goes down to 33 %. In one of those studies a 30 % of the interviewed people declared to be receiving medical attention due to insomnia or nervous breakdown caused by noise (Feijoo 2009). The social surveys data show that the most disturbing noise source is people in the streets at night, followed by the music emitted by discos and pubs. It is unclear the effect of traffic, since only in one study it is included as a specific option for night noise. We can draw some conclusions, though, from studies VA96 and SC03. In the first one measured noise levels are higher in a place for which the main source is traffic than in a place where the main source is related to nightlife activities (Guijarro et al. 1996). The sleep of people is however affected in the opposite way: 33 % have difficulties in falling asleep (traffic) vs 58 % (night life); and 22 % are awoken by noise during the night (traffic) vs 42 % (night life). In the second one, people were interviewed in the next morning after measuring levels (Feijoo 2009). During quiet nights, with traffic as the main source, there was only a 4 % that manifested being awoken by noise and nobody had problems to get asleep. During noisy nights 40 % had troubles falling asleep and 56 % were awoken by noise.

## CONCLUSIONS

Night noise is an important source of problems in Spain. Levels higher than 55 dBA in the outside are commonplace, with both traffic and nightlife activities as the main sources. Nightlife activities contribute to aggravate the situation, weekend nights being particularly problematic, with increases in both noise levels and in the spread of those levels. As a result, sleep quality is seriously affected. Whenever data about sleep problems is available, it shows that a good percentage of the people affected by noise (roughly between 20-60 %) are likely to develop insomnia and some of them will probably have to receive medical attention.

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